

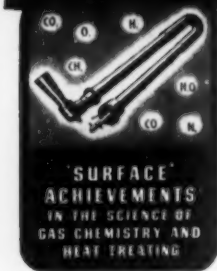


# METAL PROGRESS

APRIL, 1947

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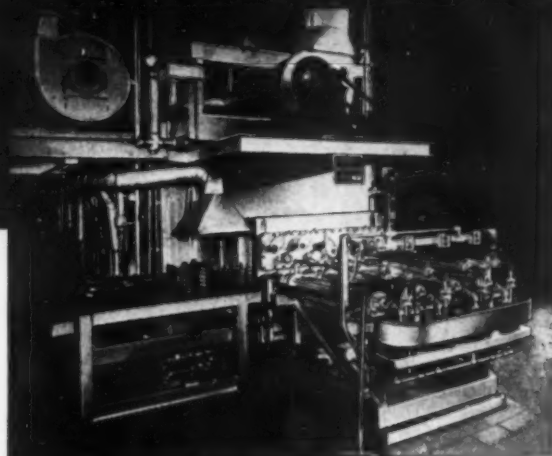
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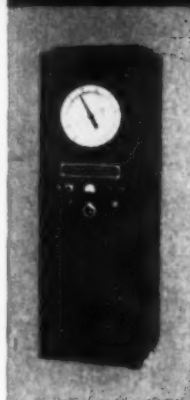
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# METAL PROGRESS

ERNEST E. THUM, Editor

APRIL, 1947

VOLUME 51, NO. 4

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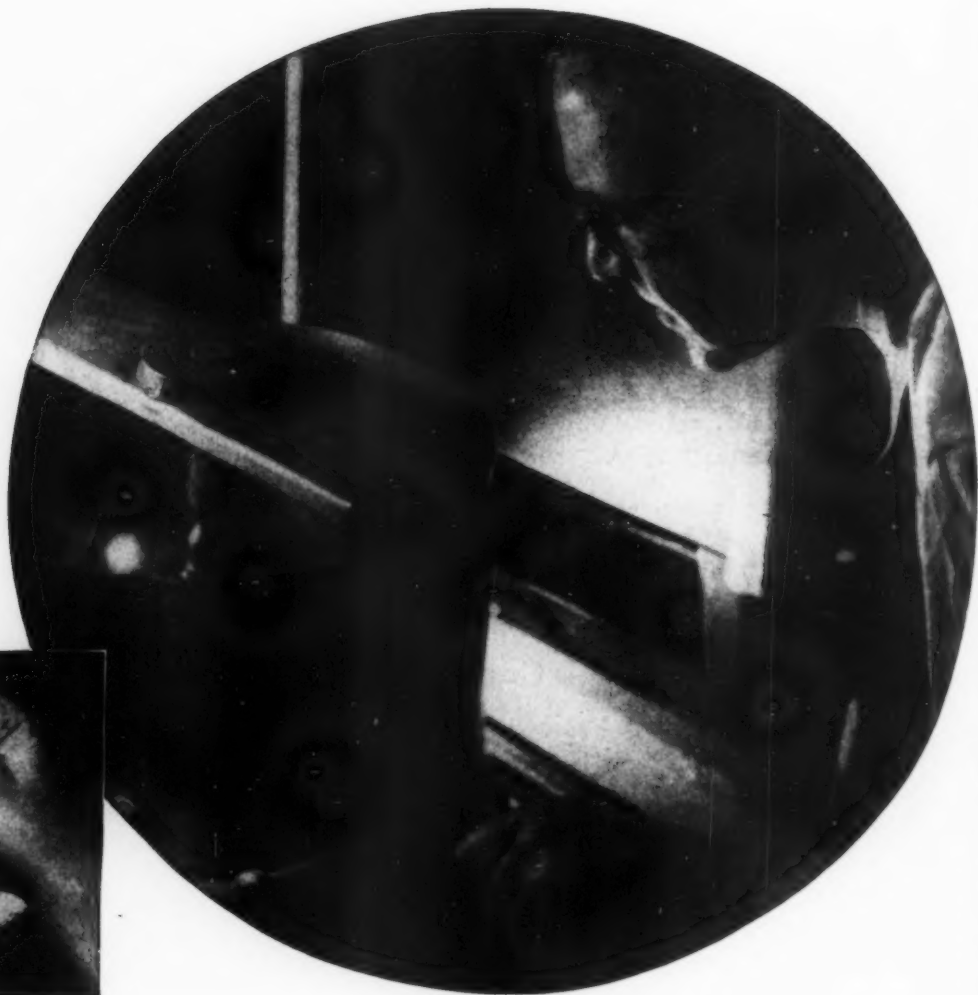
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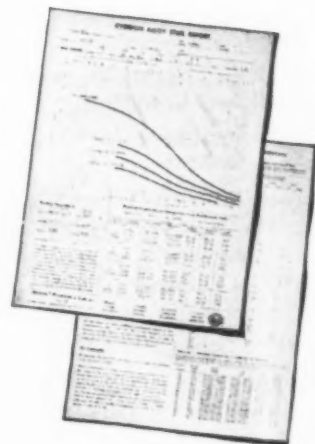
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# RYERSON STEEL



*Inoculation of cylinder block iron, by adding 1% of silicon carbide briquettes and 5% of limestone to the cupola mix, pro-*

*duces a very hot, fluid iron of improved soundness, cell size, graphite type and distribution. Machinability of the castings is*

*improved, despite higher strength, hardness and wear resistance. Leakers in the pressure test have been reduced.*

---

## THE SILICON CARBIDE ADDITION IN GRAY IRON AUTOMOTIVE CASTINGS

By E. A. LORIA, F. S. KLEEMAN, and A. P. THOMPSON\*

Mellon Institute, and Kerchner, Marshall & Co., Pittsburgh

---

THIS PAPER describes a method of inoculation that obtains, in practice, those effects considered essential to the production of automotive castings possessing a very dense grain structure together with a high degree of machinability. Growing out of many studies on the use of specially processed silicon carbide in cast iron, the method was developed recently and has been successfully applied to automotive castings which must meet pressure requirements, be heat and wear resistant, and also have satisfactory machinability in mass production.

In order to meet all these requirements, many difficulties are involved. Ordinarily, if the iron is made strong and dense enough to prevent leakage and possess good wear and heat resistance, it tends to chill on the surface and in thinner sections, so that machining becomes difficult. When the iron is softened to meet the machining requirements, open grain structure and internal shrinkage often occur in the heavier sections,

resulting in leakers; furthermore, the amount of pearlite is reduced, the ferrite increased, and the heat and wear resistance impaired.

Many foundries have had considerable difficulty with hard spots and poor machinability in both their hard castings (of low carbon content) and soft castings (high carbon, high silicon). In addition, the high percentage of leakers on motor blocks poured from hard iron has been an ever-present problem.

To describe the scope of this investigation, a typical cylinder iron has been selected and a comparison drawn between this regular mixture and a similar one treated with silicon carbide. The microstructure has been correlated with properties and performance, which involve machinability, pressure tightness, and grain structure.

### *Operating Procedure*

In using silicon carbide in the cupola melting of iron, the addition is made directly to the charge because solution is more readily effected there than if added to the ladle. If the silicon carbide is properly briquetted, it remains intact until it reaches the melting zone. There the briquettes disintegrate and the silicon carbide goes into solution in the molten iron, the subsequent reactions resulting in a marked evolution of heat. This vigorous exothermic reaction

\*Of the authors, E. A. Loria and A. P. Thompson are fellow and senior fellow, respectively, in the multiple fellowship on abrasives sustained by The Carborundum Co. at Mellon Institute, and F. S. Kleeman is metallurgist for Kerchner, Marshall & Co. The authors are grateful to The Carborundum Co. and Mellon Institute for permission to publish the information contained in this paper. The assistance of H. D. Shephard and W. A. Brown of Kerchner, Marshall & Co. in various phases of this study is appreciated.

increases the pouring temperature of the iron and produces a corresponding increase in the fluidity of the metal and the soundness of the castings. (The silicon carbide briquettes used in this investigation are marketed under the trade name of "Ferrocarbo".)

The amount of briquettes added will depend to some extent upon the type of iron to be melted, the temperature desired in the metal bath, and the properties required in the finished castings. The addition of 20 lb. per ton of metal (1% of the charge) is very satisfactory under most conditions.

In operating the cupola, it is desirable to maintain a substantial volume of slag in order to facilitate the action of the silicon carbide. With a slag in which the components are preponderantly acid, the solution of the silicon carbide is difficult, so that the composition of the slag should contain a substantial percentage of basic ingredients. A very simple method of maintaining a correct slag is to add about 50 lb. of limestone per 1000 lb. of metal on the charge.

A satisfactory method of charging comprises laying the coke bed, charging the limestone directly over the coke, scattering the silicon carbide briquettes over the top surface of the limestone, charging the iron, and then repeating the process. It is desirable to attain fairly high temperatures in order to secure the most beneficial effects. Operating conditions which will result in a pouring temperature of from 2650 to 2750° F. (1454 to 1510° C.) produce a very satisfactory reaction.

The addition of 1% silicon carbide usually increases the pouring temperature from 75 to 100° F. over that which obtains under similar conditions where no such addition is made. This higher temperature is a factor of great importance in cupola melting, for this reason: In a cupola the iron temperature cannot be controlled directly except by adding more coke and by holding the iron in the cupola for a longer time; these procedures inevitably increase the sulphur content of the iron by absorption from the coke. With most scrap mixes, the sulphur approaches very closely that percentage where a further increase will make unsatisfactory castings, so that a means for increasing the pouring temperature and the fluidity of the metal without increasing the sulphur is of great importance.

The compositions of the cupola iron mixtures used in this report are shown in Table I. The changes made in the regular mixture were the substitution of silicon carbide briquettes for silvery pig, and making up the difference in weight with steel. Otherwise operations were substantially the same both with and without the addition.

Several chill, arbitration, and tensile test bars were obtained from both iron mixtures and tests made according to A.S.T.M. standard specifications. Then sections were cut from the various test bars and prepared for metallographic examination. A significant area of each bar was observed microscopically to justify comparisons.

### Physical Properties

The average chemical analyses, transverse, hardness, and tensile test data for the iron mixtures are shown in Table II. It is evident that the addition of silicon carbide has produced a substantial increase in transverse strength and deflection in the arbitration bar, and a decrease in Brinell hardness in the chill bar. Note also the more uniform carbon and silicon contents in the various test bars of treated iron compared to the cylinder iron made by the regular practice.

It is known that tensile strength, as one measure of cast iron quality, and Brinell hardness and chemical composition, as alternate specifications for engineering applications, do not necessarily result in irons (produced under various condi-

Table I—Cupola Cylinder Iron Mixtures

INGREDIENT	REGULAR	SiC-TREATED
Steel	400 lb.	460 lb.
Iron briquettes	160	160
Malleable pig	600	600
Silvery pig	160	75
Scrap and returns	680	680
Silicon carbide briquettes	—	25
Total	2000 lb.	2000 lb.

tions) of the same quality and possessing the same properties. The need for a simple method of correlating and interpreting these properties has been recognized and only recently has such a method been proposed.

The relationship among the tensile strength, Brinell hardness, and structure of gray cast iron was first described by R. R. Adams, in *Transactions, American Foundrymen's Assoc.*, 1942. In this paper, "Cast Iron Strength Versus Structure", he presented information on the microstructure as well as data on the composition of irons of various physical properties; he then attempted to classify these irons on the basis of their cell size, graphite size, and graphite distribution. A written discussion to this paper by McElwee and Barlow attempted to correlate the same data on the basis of the ratio between tensile strength and Brinell hardness. Recently T. E. Barlow and C.

Table II—Comparison of Cylinder Iron Tests and Structures

TEST BAR IDENTIFICATION	CHEMICAL ANALYSIS			PHYSICAL PROPERTIES			MICROSTRUCTURE	
	C	Si	CARBON EQUIVALENT	BRINELL HARDNESS	STRENGTH	DEFLECTION	GRAPHITE	MATRIX
Chill bar Regular	3.42	1.93	4.06	229			{60% Type B 20% Type D 20% mixed	Moderate amount of ferrite scattered throughout fine pearlitic matrix. Some larger ferritic areas in the Type D graphite areas.
Silicon carbide	3.39	1.82	4.00	174			{60% Type A 15% Type D 25% mixed	Moderate amount of free ferrite scattered throughout fine pearlitic matrix.
Arbitration Regular	3.52	2.14	4.23	170	TRANSVERSE 1250 psi.	0.16 in.	{60% Type B 20% Type D 20% mixed	Very fine pearlite. Considerable amount of ferrite separation in center of rosette groupings.
Silicon carbide	3.38	1.79	3.98	197	1850	0.23	{70% Type A 20% Type E 10% mixed	Very fine pearlite and very small amount of free ferrite.
Tensile bar Regular	3.38	1.84	3.99	229	TENSILE 46,000 psi.	TENSILE ÷ BRINELL 200	{50% Type D 30% Type E 20% mixed	Considerable amount of ferrite separation in the Type D eutectiform graphite areas. Matrix of fine pearlite.
Silicon carbide	3.44	1.80	4.04	217	48,750	224	{70% Type A 30% Type E	Similar to arbitration bar containing silicon carbide.

H. Lorig modified the relation by the inclusion of the effect of chemical composition (see A.F.A. preprint No. 35 for 1946). On this basis, a very satisfactory relationship between (a) graphite structure and (b) ratio of tensile strength to Brinell hardness, listed by composition range, can be formulated.

According to Barlow and Lorig, an iron with a medium cell and normal graphite structure would be obtained within the composition range 3.85 to 4.20% "carbon equivalent"\* and a ratio of 190 to 210 between tensile strength and Brinell hardness. This would be the correlated structure for the regular iron mixture which possesses a carbon equivalent of 3.99% and a ratio of 200. On the other hand, the iron treated with silicon carbide, shown in the last line of Table II, possesses 4.04% carbon equivalent and a ratio of 224 and, accordingly, should possess a very small cell, normal graphite structure. Of course, it is evident that both irons are of relatively high quality, but a direct comparison indicates that the best properties and structure, insofar as resistance to wear, heat and leakage is concerned, are obtained in the treated iron.

Also, Barlow and Lorig have shown that Brinell hardness of gray cast iron is an indication of machinability only when the carbon equivalent is in proper proportion thereto. The lower Brinell

\*"Carbon equivalent" is based on % carbon plus one-third the % of silicon.

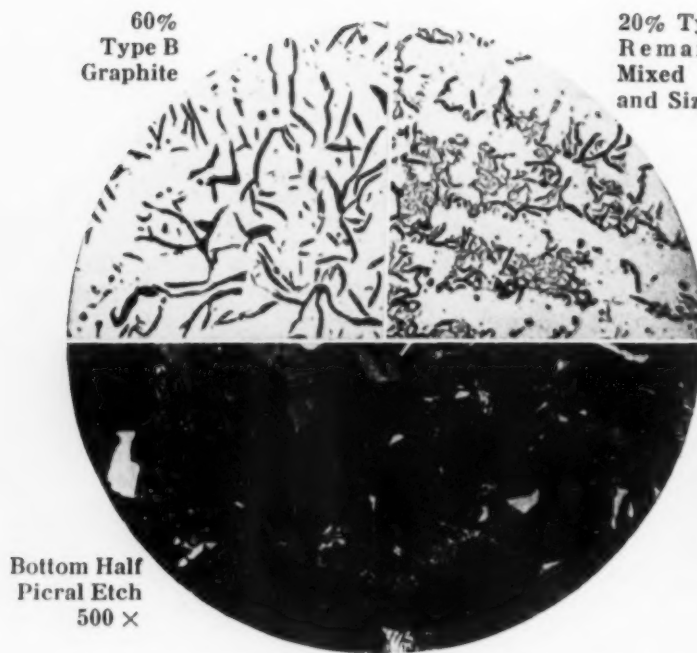
hardness correlated with the higher carbon equivalent in the treated tensile bar would indicate that it would have better machinability. Such correlations and forecasts of the properties of the two irons are confirmed by a study of their respective microstructures. Moreover, actual plant production statistics have revealed a substantial reduction in the number of leakers on motor blocks, whereby company losses from this defect have been reduced from about 25% to less than 5% where silicon carbide was added to the cupola charge. Also, machinability was considerably improved on all types of castings.

### Metallography

The theories of gray cast iron inoculation are not within the scope of this paper, but reference can appropriately be made to the recent work of H. W. Lownie on this subject, published as preprint No. 39 (1946) of the American Foundrymen's Assoc. However, a relationship between microstructure and physical properties can be drawn which will substantiate the forecasts made in the two preceding paragraphs.

It is well known that the amount, size and distribution of the graphite flakes materially affect the properties of cast iron. Due to the fact that the same factors that affect the graphite also affect the matrix, it is difficult to evaluate quantitatively the individual effects of variations in the appear-

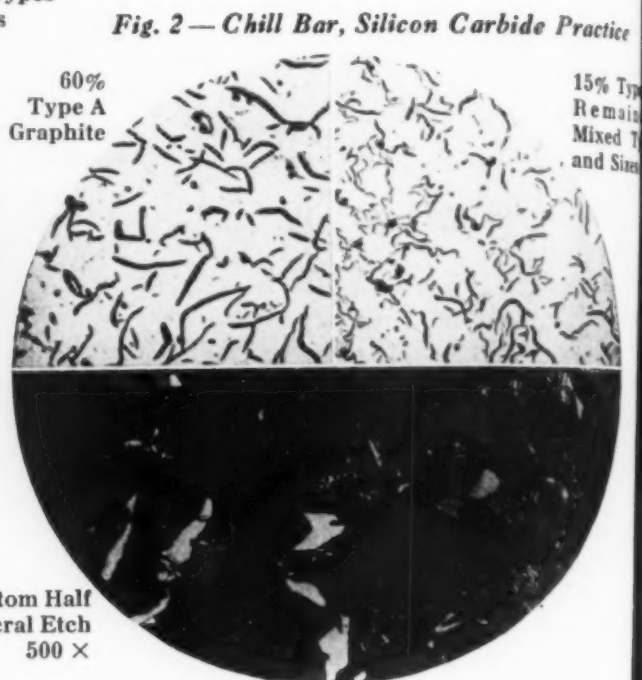




**Fig. 1 — Chill Bar, Regular Practice**

ance of the graphite. Nevertheless, a fine flake size (Type A)\* is to be preferred to a coarse size (Type C) because the former affects the continuity of the steel-like matrix less adversely. The distribution of graphite should also be given consideration because fine flake size, where poorly distributed, is actually detrimental. Such arrangements of graphite lead to continuous lines of weakness throughout the structure and are known

\*See the Data Sheet, page 616-B, for A.F.A.-A.S.T.M. standard designations of graphite in cast iron.

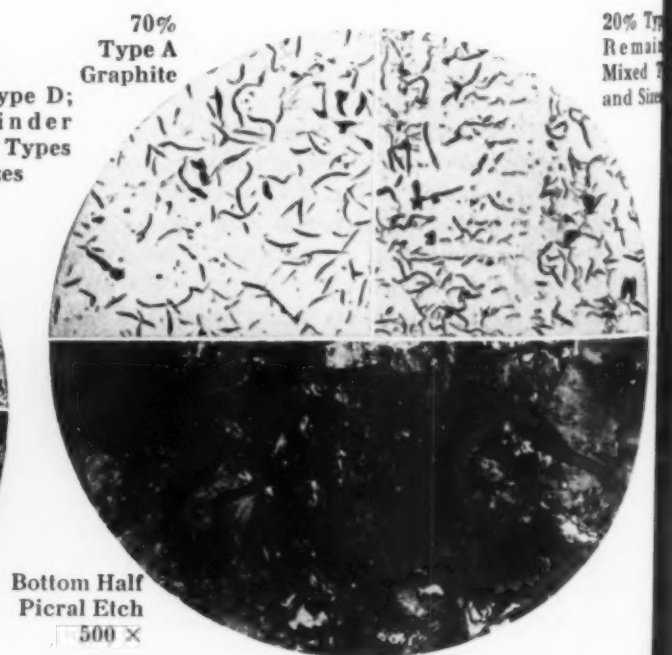


**Fig. 2 — Chill Bar, Silicon Carbide Practice**

as dendritic, eutectiform or grain boundary graphite (Types D and E). Various kinds of inoculation have been proposed as a means of improving strength by reducing the formation of interdendritic graphite. An inoculant such as silicon carbide produces a randomly distributed graphite pattern of small flakes in a completely pearlitic structure; this will be much stronger and more



**Fig. 3 — Arbitration Bar, Regular Practice**



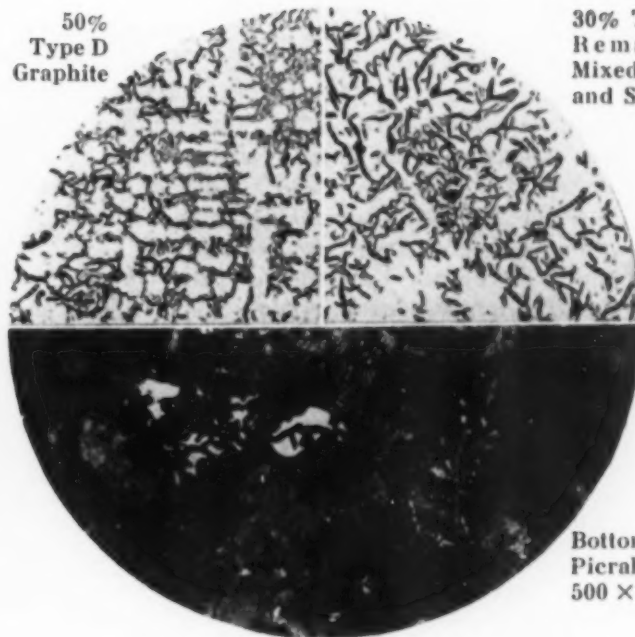
**Fig. 4 — Arbitration Bar, Silicon Carbide Practice**

**Fig. 5 — Arbitration Bar, Cast in Regular Practice, Contains a Considerable Amount of Free Ferrite in the Graphite Rosettes. Picral etch, 500×**



50%  
Type D  
Graphite

30% Type E;  
Remainder  
Mixed Types  
and Sizes



Bottom Half  
Picral Etch  
500×

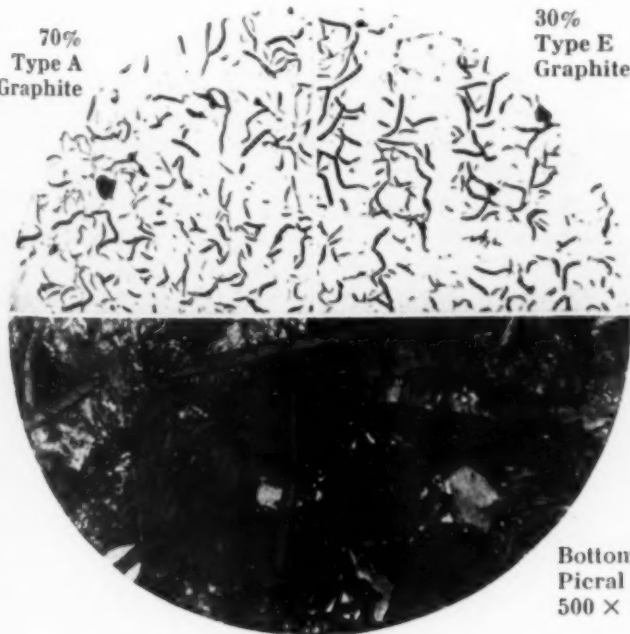
**Fig. 6 — Tensile Bar, Regular Practice**

panying photomicrographs provide visual evidence on which this classification is based. In all the engravings the two upper quadrants represent unetched sections magnified 100 diameters, whereas the bottom semicircle is the representative microstructure shown at 500 diameters, etched with picral.

**Fig. 8 — Graphite Chain Structure With Some Free Ferrite in Tensile Bar Cast in Regular Practice. Picral etch, 500×**

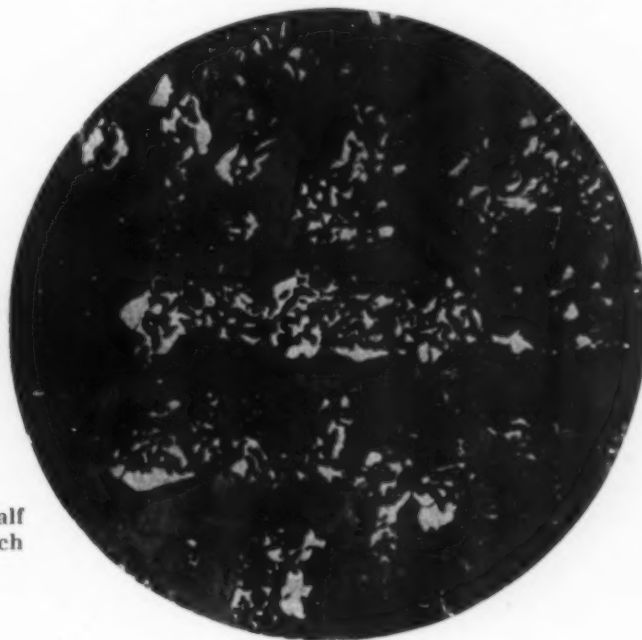
70%  
Type A  
Graphite

30%  
Type E  
Graphite



Bottom Half  
Picral Etch  
500×

**Fig. 7 — Tensile Bar, Silicon Carbide Practice**



Representative micrographs of the chill test bars are presented in Fig. 1 and 2. The structures are somewhat similar in that both contain a moderate amount of free ferrite scattered throughout a matrix of fine pearlite. The regular iron, however, possesses some larger ferritic areas in the rosettes of Type D graphite. Another apparent difference lies in the type of graphite. The major portion of the treated iron consists of Type A graphite, whereas the regular iron consists of Type B graphite. Small random (Type A) graphite flakes are more conducive to higher tensile strengths than are small interdendritic groupings or larger random flakes. This effect is not readily apparent, as the weakening influence of the small interdendritic flakes (Types D and E) obtained by rapid cooling is overbalanced by the effect of faster cooling in strengthening the matrix.

Figures 3 and 4 at the bottom of page 590 are representative of the microstructure of the arbitration bars tested. The major differences observed between the regular practice and the iron with the silicon carbide addition are that the regular iron contains 20% of the undesirable Type D graphite and, more significantly, a considerable amount of ferrite separation in the center of the rosette groupings. This is shown more pronouncedly in Fig. 5. These effects account for the lower transverse strength and deflection values obtained in the regular iron.

Typical micrographs of the treated tensile bars are shown in Fig. 7. As illustrated in the upper quadrants, the graphite is 70% Type A and 30% Type E, and the matrix structure, shown etched in the lower semicircle, is a very fine pearlite with only a small amount of free ferrite. Figure 6 contains the corresponding micrographs for the iron made by the regular practice. The inferior tensile strength and higher hardness of this iron are attributable to the graphite chain structure and considerable amount of ferrite in the Type D eutectiform graphite areas, as shown at 500 diameters in Fig. 8. In heavy sections where there is more of a tendency for segregation of the carbides, phosphides and even coarse graphite, it has been observed that the silicon carbide addition has been quite effective in dispersing such segregations.



## Summary

1. The effect of a specially processed silicon carbide, when added to the cupola mix for gray iron automotive castings, has been studied by comparing its physical properties and microstructures with those of a typical cylinder iron made according to regular practice.

2. The method of addition and the essential features of cupola operation are described.

3. Physical data indicate that the silicon carbide addition produces a substantial increase in tensile strength with no increase in hardness, an increase in transverse strength and deflection, and a decrease in chill test hardness.

4. The relative quality of the two iron mixtures has been determined. The treated iron has a higher ratio of tensile strength to Brinell hardness, and also possesses a higher carbon equivalent than the regular iron. This means that the addition has increased both the composition range and the maximum ratio, which otherwise would be limited by compositional as well as structural considerations. High values for the tensile-Brinell ratio indicate small cell size, refined graphite particles,

normal graphite distribution, and relative freedom from ferrite.

5. Employing both Brinell hardness and carbon equivalent as indicative of machinability, the data show that better machinability would be obtained in the treated iron, for it possesses a lower hardness coincident with a higher carbon equivalent. Actual plant production verifies this conclusion.

6. A metallographic study of the various test bars substantiates the correlation and interpretation of the physical properties. The silicon carbide addition is beneficial in that it promotes the formation of a small cell size, refined graphite particles and normal graphite distribution in a matrix of fine pearlite. This type of structure is known to be highly desirable in automotive castings from the standpoint of good machinability, satisfactory pressure tightness, and maximum wear resistance. Actual plant production statistics indicate a great reduction in the number of leakers on motor blocks, whereby their losses from this defect have been reduced from about 25% to less than 5% when silicon carbide was added to the iron mixture.



Accurate information on the analysis of a slag forming on a heat of openhearth or electric steel is impossible to secure

promptly by chemical means, but is available within 11 to 18 min. when a spectrograph is used. Experience with this

method shows that it will prevent three out of four of the expected off-analysis, high phosphorus heats.

## SLAG CONTROL BY ROUTINE SPECTROGRAPHIC ANALYSIS

By J. T. ROZSA\*

Chief Spectrographer, National Spectrographic Laboratories, Inc., Cleveland

FOR a good many years the problem of slag control has been how best to bridge the gap between the liquid slag in the furnace and the solid slag that is studied. Slag-metal relationships have been investigated from many divergent considerations, including the physical, chemical, and mineralogical aspects. A voluminous amount of information has been amassed but it has become increasingly apparent that a large proportion of this knowledge cannot be applied effectively at the time of its greatest possible utility — namely, during the *making* of the heat.

Especially has this problem been pertinent to the steel industry, where an old common conception still holds that "the melter makes slags, not steel". The most obvious and possibly the earliest testing procedure on the charging floor was the visual examination of the slag, whether molten or solidified. The openhearth operator had long been accustomed to the visual examination of steel tests with which to follow the various stages of his processing. It was, thus, a natural step that he should also make visual examination of his slag tests. Constant modifications and refinements of this "slag pancake test" have kept it probably the most informative method to date.

There were, however, attendant difficulties. The lack of discernment at times between standardized groupings, the dependence upon individual estimation, and other similar considerations

led investigators to seek new techniques for slag control.

Direct wet chemistry has proven too difficult and too slow for adequate application, except for determining the total iron (often calculated as FeO). An important step forward was the concept of "degree of oxidation of the slag" and its ready determination, but correlation to the degree of basicity — a major consideration — was tedious, limited, and (far too frequently) erratic.

Petrographic analysis of slag components, while a very valuable tool in the development of fundamental knowledge about slags, has been criticized for its lack of speed and for the fact that it adds difficult mineralogical concepts to the already complex job of steelmaking. These mineralogical concepts may become more familiar when X-ray units with direct-reading Geiger-Müller counters are added to the control laboratory's battery of equipment.

Recently, a method for determining basicity of slag with a pH meter has been developed by W. O. Philbrook, A. H. Jolly, Jr., and T. R. Henry and described in a paper entitled "A Rapid Laboratory Method for Estimating Basicity of Openhearth Slags", published in *Transactions of the American Institute of Mining and Metallurgical Engineers* for 1945 (page 162). This method has been applied to certain grades of steel with success, and has served admirably to re-emphasize the advantages of slag control. Technically, however, it is occasionally erratic because of its high

\*Formerly research chemist, Republic Steel Corp., South Chicago Works.

sensitivity to variables which are difficult to control in shop practice, such as rate of cooling of the sample, its mineralogical composition, and the presence of free lime. Also, because of the indirect approach, individual techniques must be developed for each class of steel at the expense of considerable preliminary work.

It is apparent that no standardized method of slag control exists. It is also apparent that the newer available methods show a distinct trend toward laboratory control.

### Spectrographic Analysis

**Scope**—One of the newest methods of analysis for the routine chemical laboratory is the spectrograph. To adapt it to slag control the premise was advanced that adequate slag control required a knowledge of slag components. Hence, the initial application was the determination of simple lime-silica ratios for oxidizing slags in openhearth and electric furnaces. This so-called "V" ratio, as proposed in Germany by Schenck in 1930, proved satisfactory, especially for normal operation, although the ratio is not a rigorous reflection of the true basicity of the slag.

After about six months of spectrographic operation in a large Midwest steel plant, it became apparent that—now and then—the performance of a heat did not conform to the usual "V" ratio. This was serious, since one of the criteria of effective slag control is the reduction of off-analysis heats (particularly those high in phosphorus or sulphur) from one, two, or three per hundred to a lower average figure. Furthermore, a special heat in an electric furnace required an unusually high precision in its control if the expected high yield were to be obtained.

A chemical check was then made to ascertain the true basicity of these slags. When the ratios were plotted against excess acid or base (in mols per 100 grams—Chipman's neutralization calculation), several points fell off the plotted mean; likewise, when a statistical study was made of good and poor performance heats according to the method of the English metallurgist, Dr. Zea,\* there was some intergrouping.

In each case the variation was caused by an excess amount of one or more of the normally unconsidered constituents—that is, MgO, Al<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>3</sub>, or P<sub>2</sub>O<sub>5</sub>. To correct for these irregular

\*"The Phosphorus Reaction in Basic Openhearth Practice", by Y. K. Zea, abstracted in *Metal Progress*, Aug. 1945, p. 291.

†"An Equilibrium Study of the Distribution of Phosphorus Between Liquid Iron and Basic Slags", by T. B. Winkler and J. Chipman, A.I.M.E. Technical Publication No. 1987 (1946).

components when found, calculation of the "V" ratio must be expanded to include them.

Presentation of basicity data by its excess acid or excess base is undoubtedly superior to all present methods, but unless it is supplemented by an extensive educational program on the charging floor, the new terminology and values would undoubtedly cause great confusion. The following calculation of the Chipman-Winkler† dephosphorization ratio has therefore been adopted

$$\text{Basicity} = \frac{\text{CaO} + \text{MgO} + \text{MnO}}{\text{SiO}_2 + 2\text{P}_2\text{O}_5 + \frac{1}{2}\text{Fe}_2\text{O}_3 + \text{Al}_2\text{O}_3}$$

to correct unusual slag conditions but still to present the familiar ratio number. It is pertinent to note that, while this ratio covers oxidizing slags when making openhearth and electric furnace steel, other ratios which the chief metallurgist feels are pertinent to his problems may just as easily be made. This same idea has been applied to electric furnace reducing (carbide) slags with somewhat greater ease.

**Technique**—Spectrographically, the technique is very simple and rapid. Essentially it consists of powdering a given slag through 80 mesh, filling a prepared graphite cup of center-post-crater design, and arcing. After developing the film, the lines of the various elements are read. The amount of individual constituents is calculated by comparing the appropriate line on the spectrum to the reference silicon line to find the concentration ratios, and a slide rule calculation to obtain the basicity ratio, or percentage constituent. (Working curves for d.c. arc and openhearth slags are given in Fig. 1.) The total time required for a lime-silica ratio is 11 min., for a basicity ratio 15 min., and for a complete component percentage only 18 min.

Since the primary function of this method is to assist the melter, the time when the samples are taken depends on his requirements and the type of heat he is making. The short time to obtain an analysis, however, allows the melter considerable latitude in regard to the number of samples, though the minimum is usually three.

Initially, when running a spectrographic analysis of slag, the lack of a matrix material to supply the conventional internal standard line was a severe handicap. To surmount this circumstance the "total energy" method of Slavin and the "ratio system" of Couliette were employed. The basis for spectrographic calculation is as follows:

$$\text{Basicity} = \frac{\frac{\text{Ca}}{\text{Si}} + \frac{\text{Mg}}{\text{Si}} + \frac{\text{Mn}}{\text{Si}}}{\frac{\text{P}}{\text{Si}} + \frac{\text{Fe}}{\text{Si}} + \frac{\text{Al}}{\text{Si}}}$$

with adjustment to molar concentration ratios.

$$\text{Also, } \% \text{ Si} = \frac{1 + \frac{\% \text{ Cu}}{\% \text{ Si}} + \frac{\% \text{ Mg}}{\% \text{ Si}} + \frac{\% \text{ Mn}}{\% \text{ Si}} + \frac{\% \text{ P}}{\% \text{ Si}} + \frac{\% \text{ Fe}}{\% \text{ Si}} + \frac{\% \text{ Al}}{\% \text{ Si}} + \frac{\text{Cr}}{\text{Si}} + \frac{\text{Ti}}{\text{Si}} + \frac{\text{Ni}}{\text{Si}} \text{ etc.}}{1}$$

wherein  $\% \text{ Ca} = \% \text{ Si} \cdot R \frac{\% \text{ Ca}}{\% \text{ Si}}$ , etc.

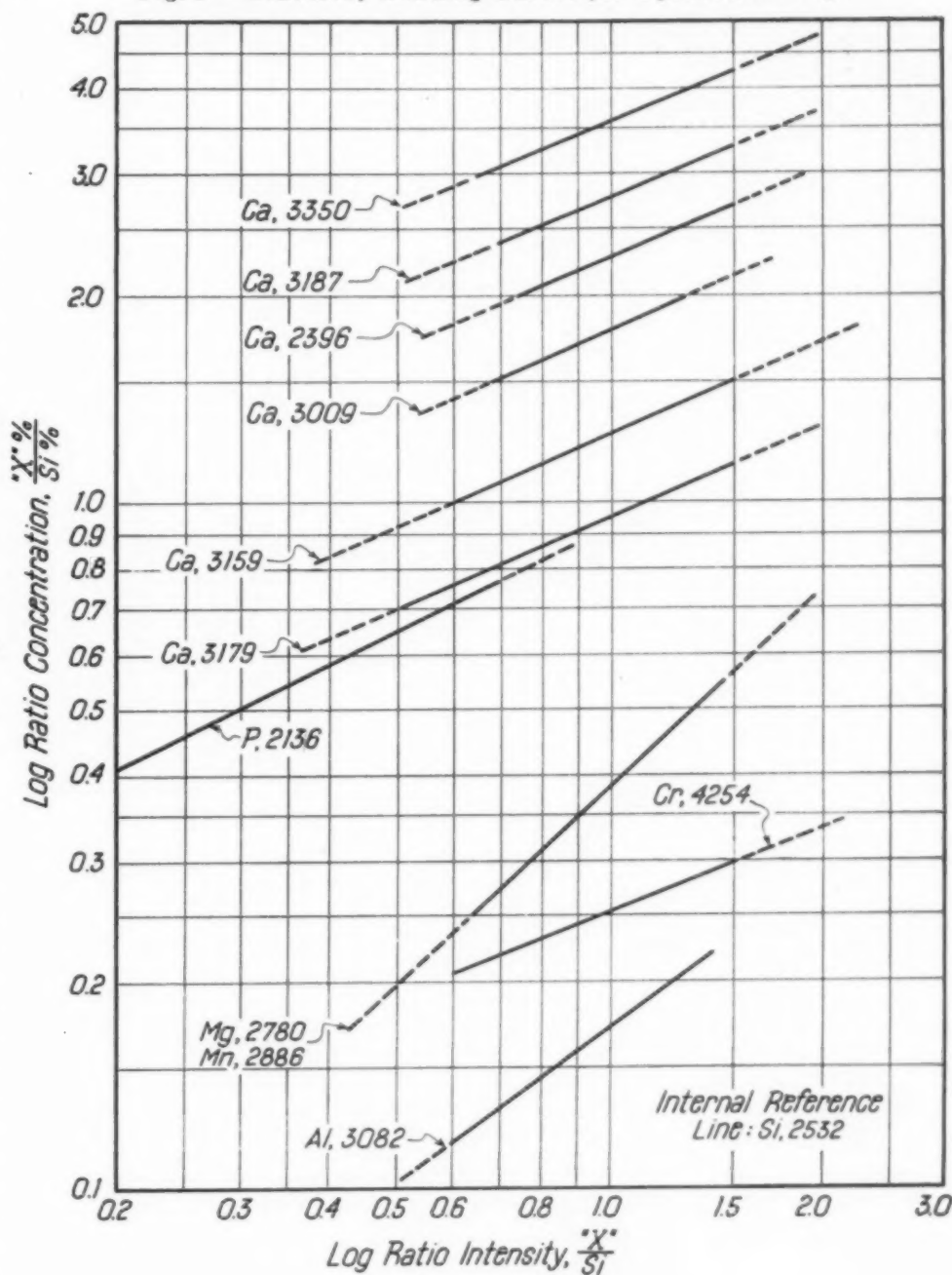
Operating conditions are given in the box on the next page designated Table I.

It will be noted that while the slag components are treated as oxides in the basicity calculation, they are determined as metals or metalloids spectrographically. For all practical purposes this is no objection—with the exception of  $\text{FeO}$  and  $\text{Fe}_2\text{O}_3$ . Only "total iron" is determined spectrographically. If the  $\text{CaO}/\text{SiO}_2$  ratio is known for a certain type of heat, the proportion of  $\text{FeO}$  to  $\text{Fe}_2\text{O}_3$  may be reasonably ascertained. In fact, one steel company in the Pittsburgh area uses the proportion of  $\text{FeO}$  to  $\text{Fe}_2\text{O}_3$ , derived chemically, to arrive at a  $\text{CaO}/\text{SiO}_2$  ratio.

Arcking characteristics of openhearth slag for both d.c. and a.c. arcs are given in Fig. 2. The total energy method is not readily applicable to the a.c. arc because of the refractory nature of the slag material and the low amperage available. Study of the elements' performance in the arc column by moving plate indicates that a fractional distillation technique would be more feasible. Further study indicated that within normal ranges of composition there appeared to be no depressant (or at least, a uniformly depressant) effect of one element upon another.

The type of slag is not limited. Openhearth and electric furnace basic oxidizing slags, carbide slags, acid furnace slags, as well as iron and lead

Fig. 1—D.C. Arc; Working Curves for Openhearth Slags



blast furnace slags, and matte have been successfully analyzed by this spectrographic technique.

**Comparison to Other Techniques**—With over a year's comparative study between visual appraisal of slag pancakes and the spectrographic technique it was found, especially by the melters of long experience, that the spectrographic method was more reliable. With the broadening of the



scope of the technique, it also became more informative.

Wet chemical analysis would require about 3 hr. for a lime-silica ratio and about 24 hr. for a complete analysis. Compare this to the spectrographic times of 11 min. and 18 min., respectively. The time advantage is even more pronounced when oxygen is used in the openhearth — a recent practice which reduces considerably the over-all time for making a heat from the present requirement of 8 to 12 hr.

To maintain this advantage, however, the laboratory must be in close proximity to the charging floor, or connected to it by pneumatic tube sample carriers. Both schemes are now utilized in practice.

A comparison of the accuracy of the method was obtained by plotting the wet chemical values of 170 slags against the logarithmic spectrographic value (Table II). Nearly all (96%) of the values fell within 0.2 ratio points of the chemical value. On repeat runs over periods of one week or less the variation is 0.13. A comparative study by the research department in another steel plant of the spectrographic against the new pH method

Table I — Operating Conditions

Spectrograph	Jarrell-Ash Co. 21-ft. grating, first order			
Filter	Neutral half and half, 12.5%			
Electrodes	Modified (Scribner) pedestal type, $\frac{3}{8}$ in. diameter			
Sample	Powdered through 80 mesh, graphite and $\text{NH}_4\text{Cl}$ added 1:1			
Excitation	FOR A.C. ARC	FOR D.C. ARC		
	Voltage	4800	40	
	Amperage	1.5	8	
	Exposure	45 sec.	45 sec.	
Wave lengths	No pre-arc		No pre-arc	
	Si	2881 Å	Si	2532 Å
	Ca	3179	Ca	3179
		3159		3159
		3181		3009
	Mg	2852		2396
	Fe	3075		3181
	Mn	2933		3350
	Al	3082	Mn	2886
			Fe	3020
			Al	3082
			Mg	2780
		P	2136	
		Cr	4254	
		Ti	3349	

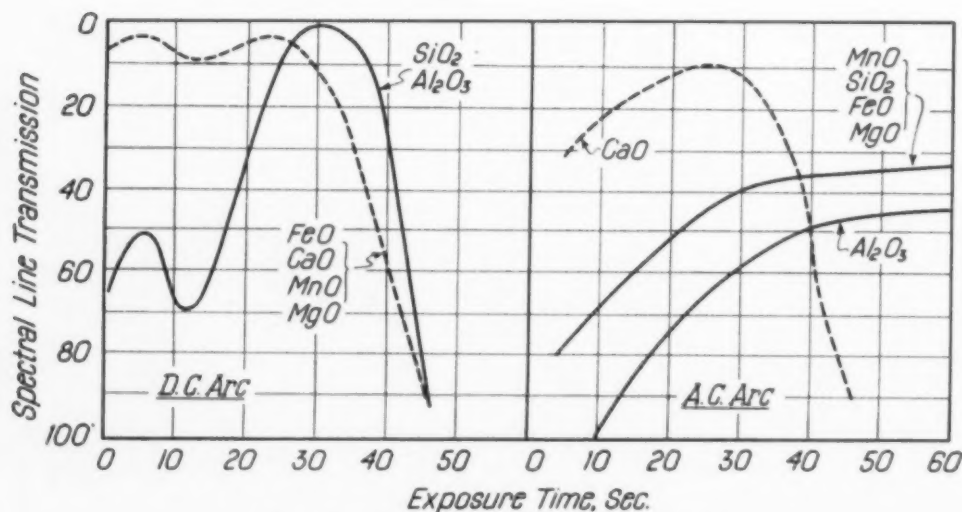


Fig. 2 — Arcing Characteristics of Slag

won an acknowledgment of greater reliability for the former.

Since the tools which the melter or first helper has at his disposal to correct for these ratios are a shovel or charging box, the accuracy of the routine method is adequate. The savings in time and cost of the analysis, of course, are appreciable.

Thus far, most of the attention has been directed toward openhearth and electric furnace slag control. The smelting furnace control does

not require the speed of analysis, but its needs are as important. Either acid-to-base ratios or complete quantitative analysis (excepting sulphur) is feasible spectrographically. Some conception of the accuracy is given by a reproducibility study for a lead blast furnace slag (Table III). Results on iron blast furnace slags, for reasons yet not clearly understood, are slightly more reproducible. In either event, these determinations would

compare very favorably in accuracy with the chemical ones, but from the standpoint of economy and time the spectrograph is far superior.

### Performance

On the initial problem of phosphorus reversion in openhearth practice, a study of over 2000 heats reveals that the average percentage of off-analysis heats due to this cause dropped approximately 75% when spectrographic control was

**Table II — Reproducibility on Openhearth Slags**

	SiO <sub>2</sub>	CaO	FeO	MgO	MnO
Weighted chemical mean	14.40	36.61	30.46	5.07	5.99
Spectrographic results	14.00	37.15	30.20	5.18	6.03
	14.60	36.95	30.00	4.97	5.75
	14.55	36.95	29.90	5.25	5.97
	14.15	36.20	29.80	5.37	5.81
	14.55	36.20	30.55	5.08	6.15
	14.30	37.00	30.60	5.11	5.68
	14.15	36.00	31.00	5.15	5.96

**Table III — Reproducibility on Lead Blast Furnace Slag**

	FeO	CaO	SiO <sub>2</sub>	PbO <sub>2</sub>
Weighted chemical mean	37.83	14.21	29.00	2.83
Spectrographic results	37.70	13.95	29.40	2.80
	38.00	14.10	29.10	2.75
	37.90	14.20	29.05	2.70
	38.30	14.15	29.30	2.80
	37.90	14.25	28.90	2.85
	37.50	14.30	29.10	2.78
	37.90	14.55	28.70	2.84
	38.10	14.60	29.00	2.77
	37.30	14.00	29.60	2.76

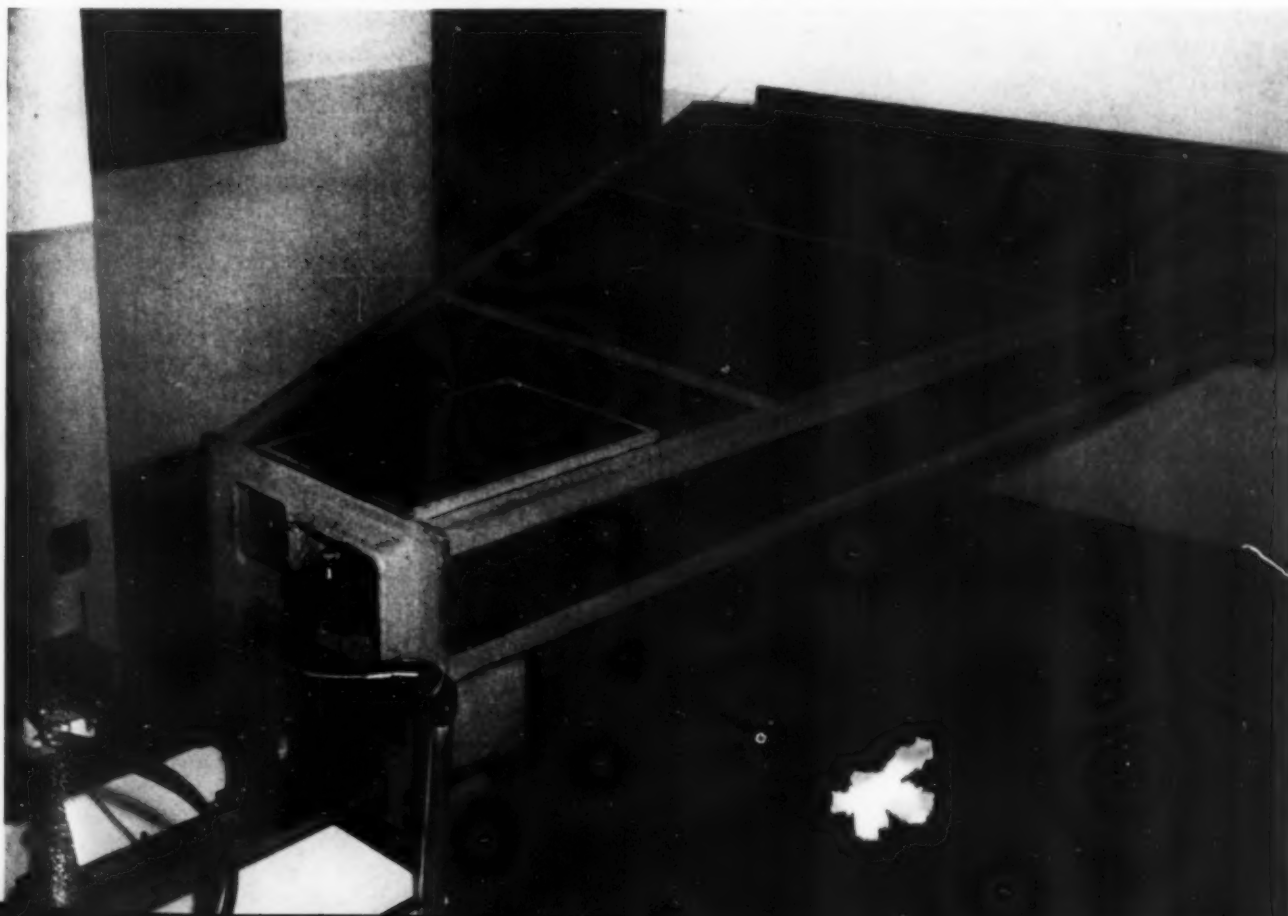
added. A further extension to a special type of electric furnace heat presented evidence that the over-all yield had been increased by a small percentage. This small percentage effected savings which within a few months equaled the cost of the spectrographic installation.

It was also found that the majority of so-called "hanging sulphur" heats have slags of low basicity. While no program had been begun, adequate slag control is less expensive than manganese additions or time delays in tapping such heats. Another consideration of slag control often overlooked is that appreciable savings in cost can be achieved through uniformity of operation and reductions in the amounts of limestone and spar.

In conclusion it may be said that spectrographic methods have now become associated closely with the new direct-reading types. These units should enable the analyst to make a complete steel or nonferrous analysis within two minutes. They should likewise make a complete slag analysis in three minutes.

It is to be emphasized that the spectrograph is not a panacea for slag control. However, it is a practical analytical tool which can greatly enhance the utilization of the voluminous information on slag control, decrease costs of production, and improve quality. Ⓒ

**Fig. 3 — Equipment for Production Control — 21-Ft. Focal Length Grating Spectrograph With Camera Mounted in Dark Room**





U. S. Army Ordnance Photo

## A Scientist Rebels

The following letter was addressed by the distinguished professor of mathematics at Massachusetts Institute of Technology to a member of the research staff of an aircraft corporation:

**I** HAVE your note stating that you are engaged in a project concerning controlled missiles, and requesting a paper which I wrote for the National Defense Research Committee during the war.

As the paper is the property of a government organization, you are of course at complete liberty to turn to them for such information as I could give you. When, however, you turn to me for information concerning controlled missiles, there are several considerations which determine my reply. In the past, the comity of scholars has made it a custom to furnish scientific information to any person seriously seeking it. However, we must face the fact that the bombing of Hiroshima has made it clear that to provide scientific information may entail the gravest consequences. The interchange of ideas, one of the great traditions of science, must receive certain limitations when the scientist becomes an arbiter of life and death.

Of course, I am acting as the censor of my own ideas, and it may sound arbitrary, but I will not accept a censorship in which I do not participate. The experience of the scientists who have worked on the atomic bomb has indicated that in any investigation of this kind the scientist ends by putting unlimited powers in the hands of the people whom he is least inclined to trust with their use. It is perfectly clear also that to disseminate information about a weapon in the present state of our civilization is to make it practically certain that that weapon will be used. In that respect the controlled missile represents the still imperfect supplement to the atom bomb and to bacterial warfare.

Guided missiles can only be used to kill foreign civilians indiscriminately; they furnish no protection whatsoever to civilians in this country. I cannot conceive a situation in which such weapons can produce any effect other than extend the *kamikaze* way of fighting to whole nations.

If therefore I do not desire to participate in the bombing or poisoning of defenseless peoples—and I most certainly do not—I must take a serious responsibility as to those to whom I disclose my scientific ideas. Since with sufficient effort you can obtain my material, even though it is out of print, I can only protest *pro forma* in refusing information concerning my past work. However, I rejoice that my material is not readily available, inasmuch as it gives me the opportunity to raise this serious moral issue. I do not expect to publish any future work of mine which may do damage in the hands of irresponsible militarists.

I am taking the liberty of calling this letter to the attention of other people in scientific work. I believe they should know of it in order to make their own independent decisions, if similar situations should confront them.

NORBERT WIENER



*Essential difference between seam welds and spot welds is that the overlapping spots comprising the seam short-circuit a*

*considerable part of the welding current, thus postheating the slugs. This extra heat has definite metallurgical action in*

*relieving internal stress and even permitting the diffusion of elements segregated during the welding cycle proper.*

## CERTAIN ASPECTS OF SEAM WELDS IN ALUMINUM ALLOY SHEETS

By GERARD H. BOSS

Aeronautical Materials Laboratory, Naval Air Experimental Station, Philadelphia\*

A SEAM WELD is really a series of overlapping spot welds. In consequence, many principles are common to spot welding and seam welding. The same fundamental equations for the welding heat generated by the passage of the electric current, that is, the  $\text{heat} = I^2RT$ , apply to both processes. Accordingly, as in spot welding, the surface resistance of the sheets must be uniform if the welds are to be of constant quality. Uniform surface resistance can be obtained either by mechanical cleaning with a wire brush or by chemical reagents. In either event the surface resistance is always lowered greatly. Hess, Wyant and their associates at Rensselaer have written several interesting and authoritative articles on the preparation of aluminum surface for spot and seam welding; two important summaries are identified in the footnote.†

Seam welding differs from spot welding in several important aspects. As is well known, if a spot weld is made too close to other spot welds more current is required to make it satisfactorily. This is because of the so-called "proximity effect", which is a bypassing of some of the welding current through nearby spot welds — short-circuited, as it were. In seam welding the spot welds are so close as to overlap, so there is a great loss of current by the proximity effect. Consequently, when

joining sheet of the same thickness, seam welds require much more current than spot welds.

The mechanism of the proximity effect is that the most recently made welds act effectively as a series of parallel resistances in the path of the current. As the diverted amperage generates heat in its path, no matter where it goes, the proximity effect serves to postheat the seam weld. This postheating has several effects. Like all postheating operations, it effects a certain amount of stress relief. Also it permits some diffusion of elements segregated by the fast freezing of the weld. This diffusion is easily proven by comparison of radiographs of seam welds and spot welds in 24S-T.

### *Methods of Examination*

For inspection or examination of seam welds the same tools and methods are used as for spot welds. Macrographs at 10 diameters of polished and etched cross sections are most informative, but it is necessary to take two sections, one along and the other across the weld. Macrographic examination is destructive and expensive but necessary, since much of the information yielded by

†National Advisory Committee for Aeronautics, progress report No. 10, "Surface Treatment of Alclad 24S-T Prior to Spot Welding", by W. F. Hess, R. A. Wyant and B. L. Averbach.

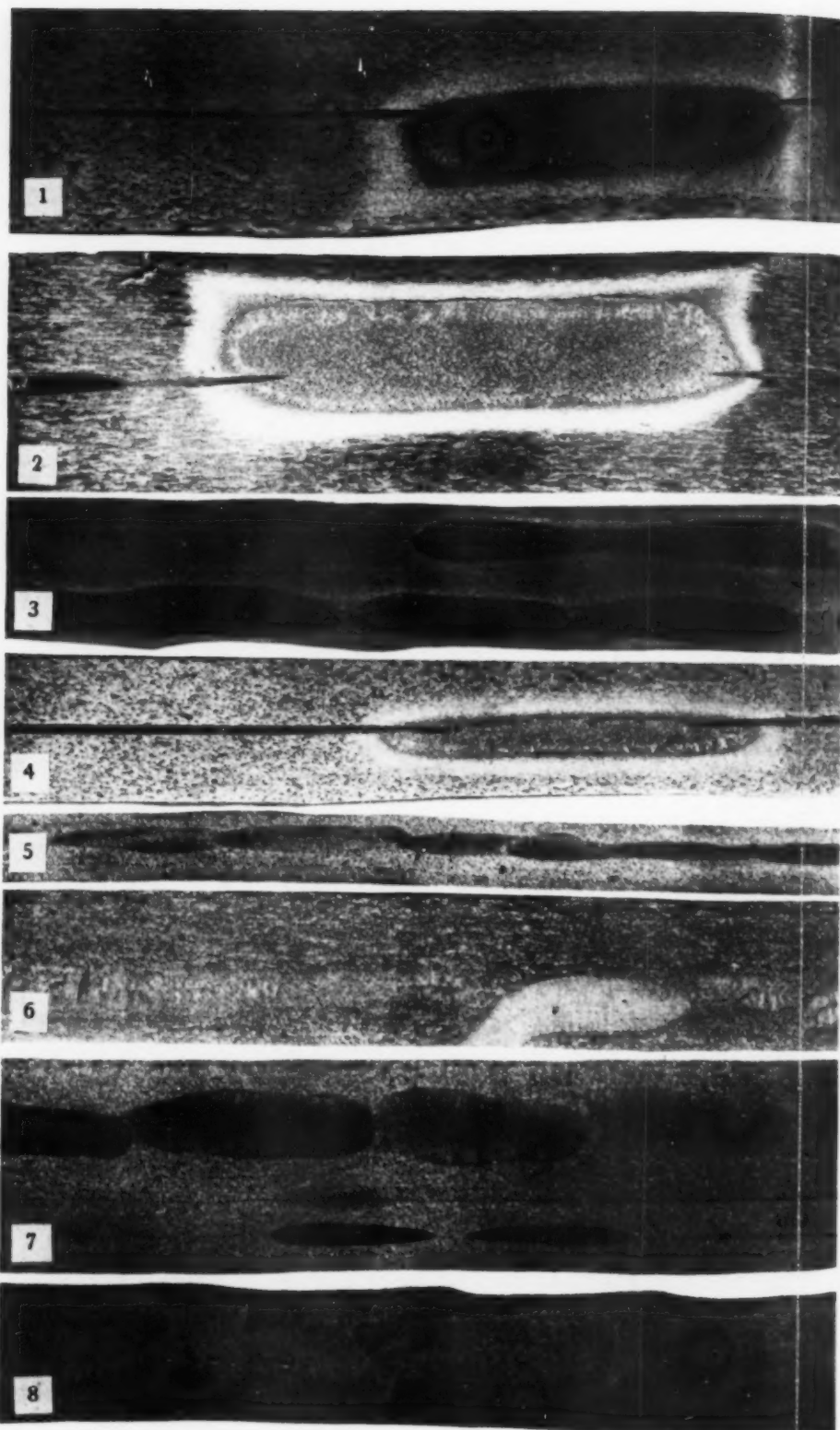
Office of Production Research and Development, War Production Board, "Final Report on the Surface Preparation of Aluminum Alloy Sheet for Spot Welding", by R. A. Wyant, T. B. Cameron and D. J. Ashcraft.

\*This paper is printed through courtesy of the Bureau of Aeronautics, U. S. Navy, and the statements are not the official view of the Navy Department, but solely of the author.

it cannot be obtained by any other means.

Figures 1 to 8 illustrate most of the defects found in sections cut in the direction of the seam and normal to the sheet surfaces. Alloys containing zinc, copper or both were etched with Keller's reagent, while the others were etched with a solution containing equal parts hydrofluoric acid, hydrochloric acid and water.

The weld should be symmetrical around the faying plane. Figure 1 shows an asymmetrical weld. Figure 2 has this same defect and also shows a type of crack found in seam welds, probably caused by shrinkage, in turn a result of insufficient pressure. Toroidal welds shown in Fig. 3 are naturally undesirable. Pinching at the faying plane, illustrated in Fig. 1 and 4, can materially weaken the seam weld if far enough advanced. Figure 5 shows an example of a slug which is too thin. Figure 6 shows a peculiar condition sometimes found in seam welds; this is unsatisfactory, since the hook of the slug coming to the surface is very apt to corrode—particularly harmful if the sheet is clad. Irregular spacing, depicted in Fig. 7, is harmful if a gas-tight joint is desired; also it indicates that the seam



**Fig. 1 to 8 — Defects and Aberrations in Seam Welds in Aluminum Sheet. Macrographs, 10 ×**

Fig. 1—Weld unsymmetrical about faying plane. Also exhibits "pinching" of the faying plane (24S-T sheets).

Fig. 2—Same defects as Fig. 1 together with an extensive

shrinkage crack (75S-T sheet).

Fig. 3—Toroidal slugs in R301-T.

Fig. 4—"Pinching" of the faying plane (24S-T sheets).

Fig. 5—Slug in 2S sheets which is too thin.

Fig. 6—Hooked slug in seam weld in 2S sheets.

Fig. 7—Toroidal and irregular spacing in 2S.

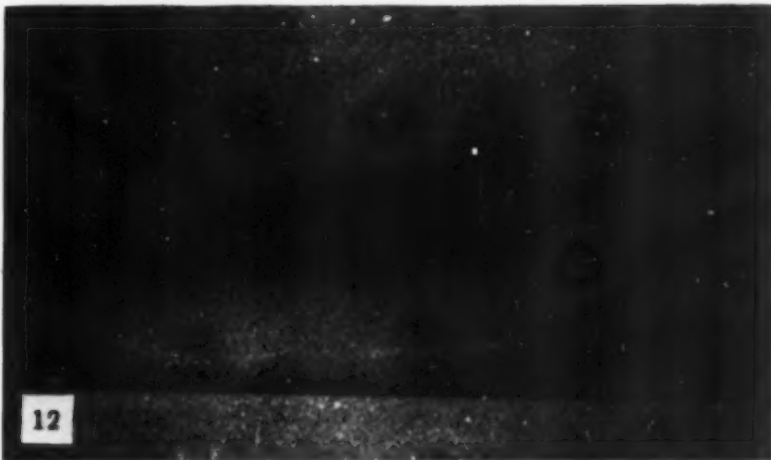
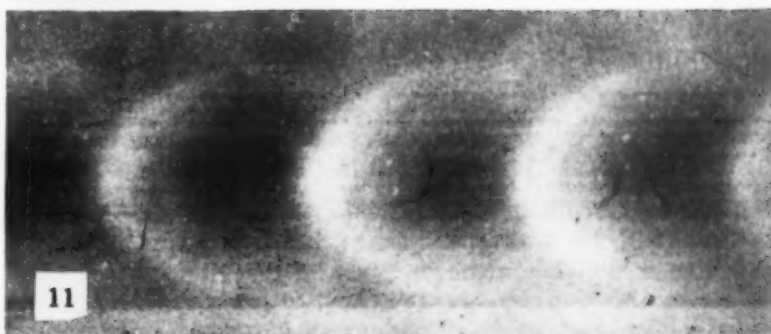
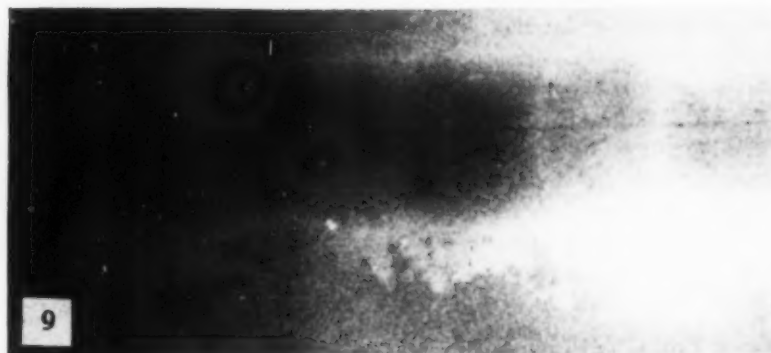
Fig. 8—Equiaxed holes in the dendritic zone of a seam weld.

welder was not operating properly, hence there are probably other things wrong with the weld, as well. Figure 8 exhibits some equiaxed voids.

Since macrographic examination does not reveal all the voids present in a seam weld, its use is limited to determining direction and extent of penetration, as described later.

Voids are the most common defect found in seam welds. Depending on the shape of their cross section they are called either cracks or holes. They are usually crooked cracks which take a radial or diametral path across the welds. Occasionally voids are found which are essentially equiaxed; these, in contradistinction to cracks, always occur in the dendritic zone. The practice of naming voids "longitudinal" or "transverse", according to whether the principal plane of the void seen in the macrograph is parallel or transverse to the faying plane, is obviously at fault. With the exception of equiaxed holes, all voids are longitudinal, in that they have a long dimension parallel to the faying plane of the weld.

Voids are certainly undesirable in both seam welds and spot welds; however, as far as is known to the present author, nobody has ever proven that they can or have caused failure. But there is one condition in which voids are obviously harmful, and that is when they reach the surface. Any weldment which contains cracks in the surface of the seam weld is unsafe and should be rejected. In order to be on the safe side, voids which penetrate the columnar crystalline zone should also be considered



**Fig. 9 to 13 — Radiograph (Magnified 6X) of Good and Bad Seam Welds**

Fig. 9 — "Spitting" in the faying plane (above the image of the spots). Also faint light lines of copper segregate just below wheel mark left of center.

Fig. 10 — Typical voids in 52S sheet.

Fig. 11 — Voids in R301-T. (The parallel shadows are grooves in the surface caused by unevenness of electrode wheels.)

Fig. 12 — Equiaxed voids.

Fig. 13 — Manganese segregation in seam welds in 3S alloy sheet.



dangerous. Such voids can grow during service, as indicated by recent work of Professor Hess who has found that voids may affect the endurance of the weld and sheet to alternating stresses.

The extent of penetration of a void can best be determined by radiographic examination. However, experience indicates that when a large portion of the seam, say over 25%, shows cracks in the radiograph, some of them will penetrate to the edge of the weld at least—if not to the surface of the sheets. Such a seam is unsatisfactory and indicates the need of radical adjustment in the seam welder.

Radiography is essential in the development of a good seam welding practice. It is nondestructive and can be applied to large areas at comparatively low cost. Since the radiograph can only reveal differences in opacity to X-rays, its usefulness is limited to searching for voids and determining whether or not there has been any "expulsion" in the faying plane. The radiographs shown on page 601 are photographs of the original X-ray picture, enlarged six times.

The original radiographs of Fig. 9 and 10 were made with a fine-grain copy film instead of industrial X-ray films; hence the detail is clearer and sharper. Figures 10, 11 and 12 show the usual appearance of voids in seam welds.

Figure 9 shows expelled metal in the faying plane. Expelled metal (or, as it is called, "spitting") is not in itself harmful, but it almost never occurs without some important defect of technique. Frequently spitting is caused by improper cleaning of the sheets or by maladjustment of the seam welder.

The parallel light lines through the weld shown in Fig. 11 are caused by grooves or uneven places in the electrode wheels.

Another condition, having no effect on the quality of the seam weld yet also revealed in the radiograph, is the segregation of heavy metals in the alloy. For example, Fig. 13 shows manganese segregation in a seam weld in 3S sheet. Upon close examination of Fig. 9 (which was taken of a seam weld in 24S-T sheet) very faint lines of copper

segregation will be discovered. Without the use of a fine-grain film it is almost impossible to discover these faint copper lines. This is in marked contrast to spot welds, whose radiographs show copper segregation as bright broad lines. The dissipation of the greater portion of the copper segregation during seam welding is due to the opportunity for diffusion afforded by the prolonged postheat provided by the proximity effect.

### *Tensile Test*

The tensile shear test is destructive and fairly expensive. However, it is the only test which in any way simulates direct loads in service. (Weaving and buckling of stressed skin puts direct tension in spots and rivets, tending to "pop" them.) Also, the tensile shear test is virtually indispensable to the machine operator when he is trying to determine the proper current setting on his machine. It is a fact that the shear strength is, within limits, a direct

function of the current when the other variables are properly controlled. With insufficient welding current the weld shears with a low load along the faying plane. As the current is increased the load required to shear the weld increases. Eventually, if enough current is used, the sheet fails in tension instead of weld shearing.

Any increase of welding current beyond this point will not increase the strength of the weld. In fact too much current will cause voids, and if the current is increased further the voids may penetrate to the surface as holes or cracks.

Too much current is not the only cause of holes or cracks in the surface of the sheets. Fundamentally, the holes are the result of too much heat, as given by the relationship  $I^2RT$ . This means that if for any reason the resistance is very high the heat will be very great, even with a satisfactory value for the amperage. Improper cleaning, which results in small areas of high resistance (as from some unremoved flux from gas welding) can therefore cause holes. In fact, under certain conditions holes a half-inch in diameter can be made; brilliant arcing occurs through the sheets, and the surface of the electrode wheels fuses at the arc.



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# CRITICAL POINTS

By THE EDITOR

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**“WHY MENTION THAT?”** is the question raised by a reader of the article in February's issue on potential hazards in molten salt baths. The dear man doubtless thinks that accidents never happen. They *may* happen even if intelligent care is exercised. If ignorance is abroad, they are practically certain. Fresh in mind is the instantaneous demolition of an electroplating shop in Los Angeles wherein 15 persons were killed. Vanished without trace also was the “expert” in electrolytic polishing, who didn't know that perchloric acid was touchy when a wee bit warm.

## *Beware perchloric*

**RELATEDLY** catching up with air-age tempo by a first personal plane trip to Wright Field (where else better?) to the magnesium exhibit (what object more *a propos*?). There, was particularly glad to see so many articles made of the light metal for JOHN R. CITIZEN and his family, such as hand luggage, baby strollers complete with bumpers fore and aft and parcel hamper, folding chairs and tables, beautiful ladders weighing 1 lb. per ft. and costing \$2 per lb., wheelbarrows, griddles and bake pans, canoes, skis, lawnmowers (would I be a sissy to get one with an engine drive?). Most of these articles have much eye appeal; it is to be hoped they can be priced as attractively. Indeed, methinks the problem of competitive costs is the paramount one to be solved by the magnesium industry. . . . There were also many applications in industrial machinery — ranging from the portable air drill to a van body complete — but all too few of these in comparison with the wealth of parts for ordnance, aircraft and signal corps. Seemingly, the trouble with magnesium right now is that peace-

time industrialists are not nearly as enthusiastic about the metal as are the officers in uniform. The military uses can go right ahead on the basis of performance and light weight. For example, magnesium castings are used almost exclusively by both Army and Navy air services for landing wheels. Yet consider this in a peacetime machine: An 89-ft. wool-spinning mule of magnesium alloy that weighs 1074 lb. less than its malleable iron counterpart and costs 50% less to machine. Or look at the surprising cups and draws made on warm sheet — equivalent to anything ever done by steel fender stock.

**DISCUSSED** with L. B. HUTCHINSON, of the Bureau of Aeronautics, Northrup's all-magnesium pusher plane XP-56, but more especially the magnesium wing panels on an SNJ-5 aircraft on display after some 1200-hr. test flying from the Naval Air Station at Pensacola. In this time — about two years — the ground crews and repair men have become familiar with the “new” metal; also the resistance to salt spray has been definitely evaluated. These wing panels are about 10% lighter than their counterparts in aluminum that

## *Properties required by aircraft designers*

are standard for this ship — a figure apparently a measure of refinement in the design of this particular wing. In other words, if similar attention to tapered members, lightening holes, and so on had been given to the aluminum wing in production, the difference in weight would have been inconsiderable. In the very large wings for ultra long range ships, the true monocoque design of wing in magnesium appears to come into its own, for then the skin can be quite thick and safe against buckling, and the clear interior provides for larger fuel tanks. Doubtless these considerations also apply to small craft for

high performance, where a thick skin would have good local stability and therefore good aerodynamic effect. . . . Weight, bulk and strength, of course, are not the only requirements for aircraft materials. Manufacture must not be too difficult, and toughness under extremes of temperature and impact — high explosive 20-mm. gunfire, for example — must be sufficient. As an instance, the exhibit contained tail booms from P-61's, one made of magnesium alloy J-1h (42,000 psi. ultimate and 3% elongation), another of magnesium alloy FS-1h (38,000 and 5%), and another of the standard aluminum alloy 24S-T (64,000 and 17%). The boom made of the stronger magnesium alloy cracked when hit by high explosive steel; the boom made of weaker but more ductile alloy FS-1h resisted such conditions as well as the one made of 24S-T. . . . Fire is also one thing that frightens some tentative users of magnesium, knowing that magnesium makes good incendiaries and the powdered metal is an ingredient of improved explosives. However, it has been amply demonstrated that magnesium sheet, castings or forgings must *melt* before they ignite, and any fire hot enough to melt the magnesium would be disastrous to any other material of aircraft construction. The confidence that is being reposed in magnesium is evidenced by the construction of Douglas's new "Skystreak" jet plane, whose fuselage is true monocoque design, sheets 0.140 in. thick literally wrapped around the engine with the minimum of clearance.

**J. B. JOHNSON**, chief of the materials laboratory of the Army Air Forces, spoke of efforts at Wright Field to perfect magnesium alloys of good creep resistance at moderately elevated temperatures. During World War I, the British developed Y alloy in aluminum, whose counterpart today is No. 142, used in "high" temperature service. Of

#### *Good alloys for hot spots*

the commercial magnesium alloys, EM62 (a German alloy with 6% cerium, 2% manganese) has the best short-time high-temperature strength — in fact better than Y alloy at 550° F. and above. Experimental alloys of this sort, with zirconium as grain refiner, are now being studied. Cobalt, beryllium and cadmium are each advantageous additions. One of the best of these experimental alloys has better creep properties than Y alloy at 600° F., even though its room-temperature strength and elongation are lower. . . . Some sheets about 50% stronger than present standard alloys have also been made of such a remarkable *potpourri* as Mg-Ag-Cd-Zn-Zr. Furthermore, the old alloy AZ92 can be melted and cast without flux and without

danger of burning when as little as 0.01% beryllium is added. Ah, but there's a catch! The grain is tremendously enlarged and strength and ductility cut in half. A little zirconium recovers about half this loss, but the complete cure has not yet been found.

**INCENDIARIES** as well as "improved" explosives have depended so much on magnesium or fine, granulated aluminum that this sinister use will doubtless bear heavily on men's minds for years. It has often been stated that the overexpansion of magnesium capacity was due to a bad guess by the general staff as to the quantity of incendiaries needed to burn down Germany, Italy and Japan. Originally fire bombs had magnesium canisters that were ignited by thermit (aluminum powder and iron oxide). Later the incendiaries were

#### *Metal improves even explosives*

packed with a sticky oil-jel mixed with magnesium granules. . . . Aluminum powder was early found to be a good addition to the super explosive RDX, developed at Woolwich Arsenal in England (although the Germans knew about it too). Torpex, 50 to 100% more damaging than trinitrotoluene, is a mixture of TNT, aluminum powder, and RDX; first used in 1941 it increased considerably the destructive zone around a depth bomb. The function of the aluminum is to increase the heat at the focus by its almost instantaneous combustion. (The Germans used a 50:50 Mg:Al mixture.) HBX is like Torpex, except the metallic particles are waxed to reduce friction from bumps or normal handling and processing. Tritonal is a mixture of TNT and aluminum powder — it is fine for those two-ton block busters that became obsolete when we discovered the possibilities of U<sup>235</sup> and Pu<sup>239</sup>. And finally Minol is the Britisher's name for TNT+NH<sub>4</sub>NO<sub>3</sub>+Al, a mixture used in submarine mines. . . . At war's end vast quantities of "atomized" aluminum became surplus. Do you have any use for it? — the War Assets Administration is selling it cheap. It is commercially pure metal, melted and granulated by blowing through spray guns under such conditions that about half of it is — 325 mesh.

**FOOTNOTE** on obsolescence (something that catches up with you while you're resting). A quotation from "The Lady's Almanac for 1859" follows: "Though coaches and omnibuses are not as yet moved by steam, we (of Boston) traverse the streets of the city and its adjacent thoroughfares in cars, on iron tracks — the prettiest, safest, and most expeditious mode of conveyance, next to that of steam, that could be invented."



NEWS that the U. S. Steel Corp. is building a very large plant to study the concentration of low grade iron ore in Minnesota, despite the fact that the Corporation already owns the lion's share of the remaining ore in the Ranges, emphasizes the fact that all bonanzas are eventually exhausted—even the amazing Mesaba. Of course much

### *A forward look at iron ore supplies*

Minnesota ore has been crushed and washed in the past—about one-seventh of the total shipments are concentrates of this sort. There is a metallurgical limit to this practice, as the average silica in these concentrates (11%) is much higher than "open-pit direct-shipping" ( $8\frac{1}{2}\%$   $\text{SiO}_2$ ), and therefore undesirable for blast furnace smelting except when mixed with the latter. The other mining companies in the Lake region have already given much study to the low grade material—an astronomical amount of country rock called taconite that blankets northern Minnesota in a bed 100 miles wide and 600 ft. thick. This contains about 50% silica and 30% finely disseminated iron particles (magnetite and hematite). The problem is to crush and fine-grind this hard and brittle rock, separate the values magnetically and by flotation, and sinter or nodulize the concentrate—and do it by the million tons every day and at a cost that will compete with high grade iron ore from foreign countries.

FUNDAMENTALLY the same problem exists in the Alabama deposits of Red Mountain. There the mining is underground; the seams of workable ore are such that a large percentage of it will be lost unless some way is devised to convert the adjacent country rock into blast furnace feed.

### *Concentrating Alabama ore*

Republic Steel Corp. has a real ore concentrator down there, which takes a highly siliceous "ore" from an enormous but otherwise unworkable seam. It is actually a ferruginous sandstone consisting of fine silica grains, about 100 mesh, cemented together with hematite. This rock is fine ground, the iron oxide scrubbed off the silica grains, and the two separated by hydraulic classifiers. The thin red slurry is thickened and filtered, the filter cake dried, mixed with fine coal and sintered. In this way 2 tons of feed with 35% iron and 28% silica is converted into 1 ton of desirable blast furnace sinter having 50% iron and 19% silica. But—it costs money!

IN THIS SAME REGION is another operation which is of interest in this same connection. Near Birmingham the U. S. Steel Corp. has a plant

where crushed ore from eight mines in Red Mountain is further broken and separated into coarse ( $+\frac{3}{4}$  in.), medium ( $+\frac{1}{4}$  in.) and fine (through  $\frac{1}{4}$  in.), the two former categories being stored each in its own 800-ton silo, from which it

### *Value of sinter in furnace burden*

is drawn at any time and at any desirable rate. ROY YINGLING, the superintendent, said that this accurate mixing of the ores is a necessity, because the iron content (about 37%) is low, and the gangue varies (mine to mine, and seam to seam) from very basic in nature with excess lime to one that is fairly siliceous; the mixture must be balanced to be as near neutral or self-fluxing as possible. . . . Some 18,000 tons of ore produce 4000 tons of fines daily; this is mixed with the blast furnace flue dust and whatever coke breeze is available, moistened in pug mills, and sintered in three large Dwight-Lloyd machines (traveling grates, on which a thick layer of fines is spread, the top surface ignited, and air drawn through by suction into a wind box below, thus supporting combustion and generating enough heat to fuse the material into a spongy mass). Blast furnace flue dust contains about 18% of coke dust, and can be mixed with three times as much ore and still furnish enough fuel to do the job—real, efficient combustion, one might say. Blast furnaces at the Ensley and the Fairfield plants have now operated for six years on this sized, balanced ore, low in fines, and carrying about one-fourth its iron in a porous, dry, permeable sinter. The associated improvement in stock and blast distribution has noticeably increased the output of pig iron, lowered the coke consumption, and made for a much steadier production, free from many of the time-honored and long-endured vagaries of blast furnace operation. . . . This is one of the hopes entertained by those long interested in the concentration of the Minnesota taconites—namely, that the savings at the blast furnace, when smelting a sintered concentrate, will counterbalance most of the cost of concentrating the ore.

THE DESPERATE need for publications to serve as tools of physical and intellectual reconstruction abroad has been made vividly apparent by

### *Books and world recovery*

appeals from scholars in many lands. The American Book Center for War Devastated Libraries, Library of Congress, Washington, D.C., is renewing its appeal for technical and scholarly books and periodicals in all fields, particularly for the past 10 years. Especially welcome would be complete or incomplete files of *Metal Progress*. ☉

For those who are contemplating a change from mechanical to electropolishing but who have been bewildered by the multiplicity of suggestions concerning

apparatus and solutions (the apparatus, by the way, can now be bought complete in its own cabinet from equipment manufacturers) the following article

describing the simple circuits and trouble-free electrolytes long used by a Westerner for steel and aluminum samples will be of interest.

## METALLOGRAPHIC ELECTROPOLISHING

By J. L. WAISMAN

Plant Metallurgist, Douglas Aircraft Co., Inc., Santa Monica, Calif.

**E**LECTROLYTIC polishing for metallographic purposes is now developed to the point where many laboratories have adopted the technique as routine, either in place of, or in addition to, mechanical polishing. Other laboratories, however, have abandoned the method after trial, dissatisfied with some of its characteristics. Many of the earlier electrolytes required special time-consuming precautions to prevent explosion during mixing, and had to be cooled during use; some installations required a clumsy change in setup for different alloys and types of samples; some required preliminary calculations and adjustments for each polishing. Most of these earlier objections can be overcome by proper choice of the electrolyte, proper cell design and construction, and simplified technique based on an understanding of the principles involved.

This paper will discuss the mechanism of electrolytic polishing, the essential features of an electropolishing installation, and the factors entering into mechanical convenience. A detailed description of the installation and electrolytes used by the author for the routine polishing of steels and aluminum alloys is included.

For an extensive bibliography the reader is referred to "Electrolytic Polishing of Stainless Steels and Other Metals", by Otto Zmeskal, *Metal Progress*, April 1945, p. 729.

### Principles of Electropolishing

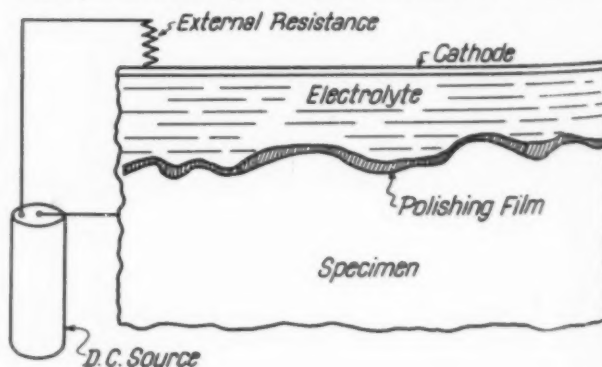
**Polishing Mechanism**—While details of the mechanism of electrolytic polishing are not completely established, the following mechanical pic-

ture of the reaction will help the student to understand the effect of variables.

The surface of the specimen initially consists of a series of peaks and ridges somewhat as sketched in Fig. 1. When the specimen is made the anode of an electrolytic polishing cell (connected with the positive pole of a battery or other source of direct current), some of the metallic atoms from the specimen dissolve in the solution as positively charged ions, thus carrying the current through the electrolyte over to the cathode (a suitable piece of immersed metal connected to the negative terminal). Because of this migration of ions, the portion of the electrolyte in immediate contact with the specimen is of a different composition from the remainder of the electrolyte. This boundary layer usually forms a visible film on the specimen.

For purposes of simplification we may assume

Fig. 1—Sketch of Elements of Electrolytic Cell for Polishing a Slightly Roughened Surface



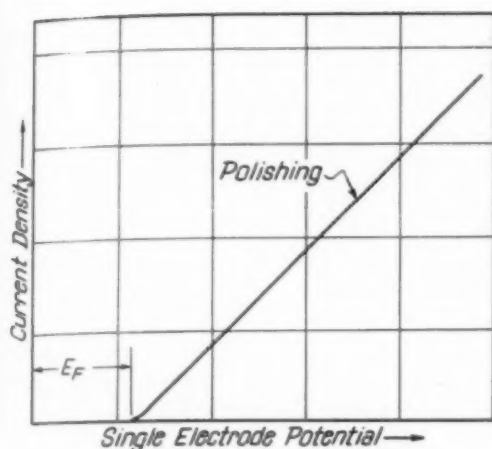


Fig. 2—Relationship Between Current Density and Single Electrode Potential for Solutions That Have a Polishing Action Over a Wide Range of Voltages and Currents

forms on the specimen and no current passes until the single electrode potential exceeds the "back emf.",  $E_F$ . From this point on, the current increases in proportion to the voltage. At the lower voltages in the so-called straight-line region, etching but no polishing occurs, presumably because the film does not build up in sufficient thickness to remove material selectively from the peaks. As voltage increases, the polishing reaction predominates over etching,

and the polishing rate increases. Indefinite voltage increases are limited by the advent of uneven polishing or undulations caused by the accumulation of large gas pockets on the specimen. (The undulations caused by high current densities should not be confused with the very mild undulation normally present in most electrolytically polished surfaces. The latter is not objectionable in metallographic work.)

Electrolytes that show this type of current-emf. relationship

will polish over a wide range of current densities; in general, high current densities are attainable and result in rapid polishing. The electrolytes described later on for polishing steels and aluminum alloys are of this type.

Another type of relationship frequently encountered is shown in Fig. 3. In stage 1, the current density increases in proportion to the potential increase. Metal will dissolve in this stage but the specimen will have a dull, etched appearance. In stage 2, the polishing film is formed on the specimen. As the film is formed, the back emf. of the film,  $E_F$ , and film resistance,  $R_F$ , both increase and cause the current to drop somewhat. Finally, as the film concentration increases, an equilibrium is reached at which the film in contact with the specimen becomes virtually saturated in metal ions. During stage 3 the stable film maintains its equilibrium and no increase in current is obtained, despite an appreciable potential increase. Polishing occurs during this stage. When a given limiting potential is

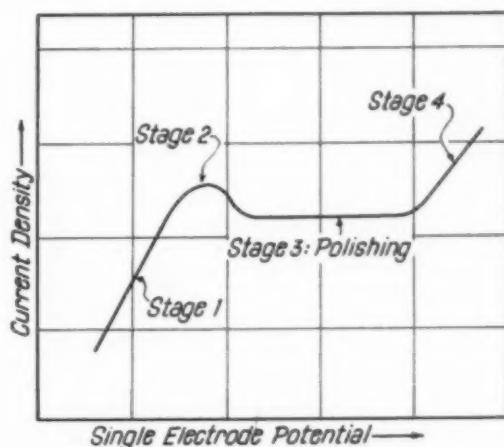


Fig. 3—Electrical Conditions for Electrolytes that Polish at a Substantially Constant Current Density

that this film is thinner at the peaks than at the valleys and has a higher electrical resistivity than the remainder of the electrolyte. (This thinning of the film at the peaks might be ascribed to the more rapid diffusion of the electrolyte away from "peak" locations.) At any rate, the film at the peaks will have a lower resistance and a higher concentration gradient than the film at the valleys. As a result, the current density at the peaks will be higher than at the valleys and the resulting action will be a selective removal of the peaks. This is the essence of any polishing action. A polishing electrolyte must, then, be capable of forming a high-resistance polishing film at reasonable voltages.

Such electrolytes are not necessarily explosive; it is only a coincidence that some of the electrolytes first used for polishing were explosive mixtures. The commonly used electrolytes form films having one of the two types of electrical characteristics to be described in the following paragraphs.

Assume that we could measure the electromotive force, emf., across the specimen separately from the rest of the circuit while a current  $I$  is passing. This emf. is usually termed the "single electrode potential". If we were to increase progressively the single electrode potential and take simultaneous readings of potential and current, relationships would be found similar to those shown in Fig. 2 and 3.

Figure 2 shows the simple relationship where polishing occurs at any one of a continuous range of voltages and currents. At low voltages a film



reached, stage 4 begins. During this stage a new reaction takes place at the electrode (usually the liberation of oxygen) and the new reaction products break up the polishing film sufficiently to produce a nonuniform attack.

Some structures will etch slightly during polishing. This etching effect can be accentuated, if it is so desired, by potential settings close to stage 2.

Essentially then, in order to electropolish satisfactorily, it is only necessary to insert a specimen in a cell containing an electrolyte known to be capable of producing a polishing film on that metal, and to apply the appropriate single electrode potential to the specimen for sufficient time to smooth out the peaks and valleys. Of course this single electrode potential is a hypothetical value which is not directly measured in electrolytic cells. The electrical and electrolytic circuits must be properly designed and controlled to insure that the required single electrode potential is consistently applied to the specimen.

**Electrical and Electrolytic Circuit**—The simplest type of circuit is shown in Fig. 4 and is separated into its basic electrical characteristics in Fig. 5. The relationship between the current  $I$  passing through the circuit, the externally applied voltage  $E_B$ , the back emf. of the polishing film  $E_F$  and the resistance of the film  $R_F$ , the electrolyte  $R_E$  and the external circuit  $R_R$  is as follows:

$$E_B = E_F + I(R_F + R_E + R_R)$$

The required single electrode potential is the voltage which must be applied to the specimen to

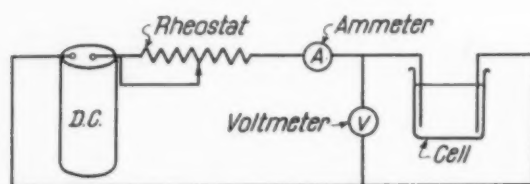


Fig. 4 — Simplest Type of Polishing Circuit

overcome the back emf. and the film resistance, and is therefore equal to  $E_F + IR_F$ .

It is apparent that the externally applied voltage must always exceed the required single electrode potential by an amount which depends on  $R_R$  (which depends in turn on the electrolyte composition and its temperature, as well as the cell dimensions), and  $R_E$  (which depends on the cathode area and external resistance). With a given specimen, electrolyte, cell, and electrical circuit, the external voltage required can quickly be determined experimentally. However, any change

in specimen area, cell or electrical circuit will necessitate a corresponding change in applied voltage to develop the required single electrode potential.

Necessity for frequent electrical adjustment can be avoided by making all resistances as low as possible. This is apparent from the above equation, since with zero total resistance, a given externally applied voltage would develop the same single electrode potential regardless of current fluctuations. Another step in simplifying control is to fix all resistances so that their variation does not require frequent manual compensation. In order to have low, fixed resistances, the specimen area and cell dimensions should be fixed, the cathode should be large and the specimen held as close to it as possible, heavy wires and good connections should be used, and the rheostat type of

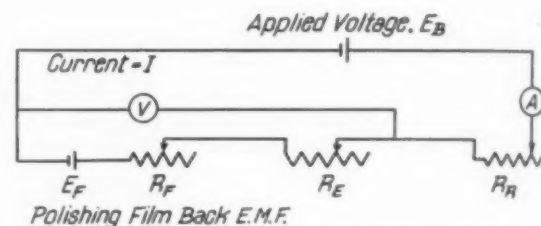


Fig. 5 — Electrical Characteristics of Fig. 4

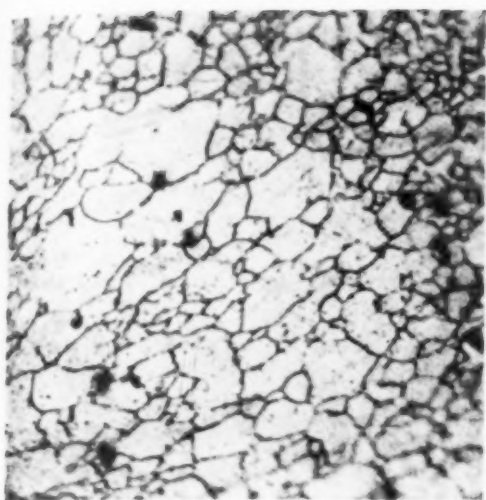
control should be avoided. The circuit having a low resistance shunted across the cell (either a fixed resistance, as recommended by Messrs. Horowitz and Maltz in February *Metal Progress*, or a low slide-wire resistance) is much more satisfactory than the simple one shown in Fig. 4, since this secondary resistance minimizes the effects of current fluctuations and heating.

Power source may be batteries, a generator, or a.c. rectifier.

The volume of the electrolyte has an important effect on fluctuations in cell resistance. Too small a quantity of liquid will heat rapidly and change the cell resistance. Sufficient electrolyte should be used so that no appreciable heating takes place; stirring will prevent local overheating.

**In summary**, to polish specimens rapidly and conveniently:

1. Select a nonexplosive electrolyte that is insensitive to slight voltage variations, and capable of operating at high current densities. Such electrolytes are available for most common alloys.
2. Design the installation for minimum sensitivity to changes in circuit and cell resistance. If possible, fix the exposed specimen area and anode-cathode distance by some mechanical means. Avoid complicated circuits, long, small-



*Fig. 6 — Improperly Annealed 18-8 Stainless Steel, 500 X. Electropolished surface somewhat wavy due to start from "cutoff" end. Etchant: 10% oxalic acid*

gage connecting wires and poor connections. Use large cathodes, small anode-cathode distances, and potentiometer-type control circuits with the secondary resistance shunted across the cell. Employ sufficient volume of electrolyte to prevent excessive heating, and stir the electrolyte during the polishing operation.

3. In establishing a polishing technique, either duplicate all features of another operating installation and use the same settings of that installation, or determine the required voltage experimentally.

### *Routine Methods for Steel and Aluminum*

Using the cell and electrolytes described below, polishes can be produced consistently, conveniently, and rapidly. The solutions described can be mixed quickly, they do not attack bakelite specimen mounts, and they operate at high current densities.

**Power Source** — Batteries, generators or rectifiers are satisfactory as a source of direct current. If continuous control is required on the d.c. line, a potentiometer-type circuit is used (slide-wire resistance shunted across the cell). For routine work, a switch is arranged so that either 36 volts or 14 volts is quickly supplied. A 110-volt a.c.

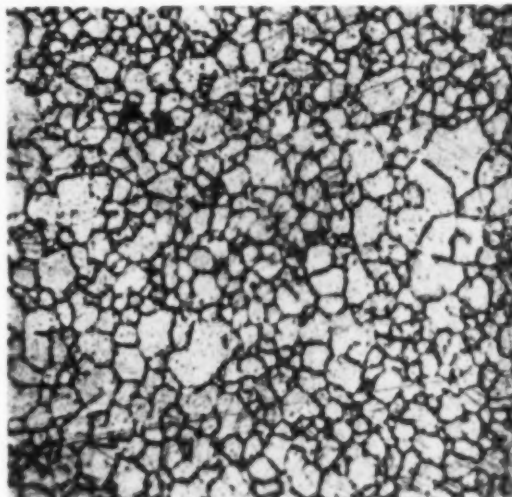
source provides power for a stirrer. The same on-off switch operates the electrolytic cell and the stirrer.

**Electrolytic Cell** — A cell arranged to "spot-polish" is employed. The vessel is rectangular and constructed of 18-8 stainless steel sheet. The interior is left bare and acts as the cathode. Ring-shaped stainless steel gaskets are tapped or welded into one end of the vessel. Rubber gaskets  $\frac{1}{16}$  in. thick are attached to the end to accommodate the specimen. These rubber gaskets are the only insulation between the cathode (cell wall) and specimen.

The specimen is clamped to the gasket by a screw clamp which makes the electrical contact. (With bakelite mounts, a hole is drilled through the back for contact.) Large pieces are held manually against the gasket. Two gasket sizes are used, one with a  $\frac{3}{4}$ -in. diameter hole for aluminum alloys at 14 volts, and one with a  $\frac{3}{8}$ -in. hole for steel at 36 volts.

Current will be between 0.2 and 3 amp.

A quick method for lowering and raising the level of the electrolyte below and above the gasket hole must be provided for inserting and removing the specimen. The author has used a  $\frac{5}{8}$ -in. hose connected to the bottom of the cell and to the bottom of an adjacent leveling bottle. Raising the leveling bottle fills the cell in 1 sec. A tilting-type cell is also satisfactory. Inside dimensions of the cell are 3 in. wide,  $4\frac{1}{2}$  in. long and 4 in. high. A



*Fig. 7 — Structure Similar to Fig. 6, But Finer Grain, 500 X. Flat surface starting from 00 emery paper*

stirring motor is fixed permanently in place above the cell and operates a glass stirring rod approximately 1 in. from the specimen.

**Instruments** — A voltmeter and ammeter are permanently fixed in the circuit with suitable fuse protection for the ammeter. Capacity of 5 amp. is provided in the instruments and wiring.

**Electrolytes** — For polishing steel a solution of 50 cc. of 60% perchloric acid with 750 cc. of ethyl alcohol and 140 cc. of distilled water is used. For polishing aluminum and aluminum alloys the electrolyte is 200 cc. concentrated nitric acid with 400 cc. methyl alcohol. (Ethyl alcohol cannot be substituted for the methyl alcohol specified since it reacts violently with nitric acid.)

Volt-ampere relationships for both these electrolytes are of the straightline type of Fig. 2. Specifically, a steel specimen of 0.25 sq.in. area

begins to polish when the voltage is about 8 and amperage about 0.6 and continues on up; at 20 volts a 2.1-amp. current is flowing. An aluminum specimen of 0.5 sq.in. area begins to polish at about 4 volts and 1.0 amp. on the circuit, and continues to polish up to and beyond 7 volts and 2.8 amp.

**Specimen Preparation**—For visual micro-examination, specimens are electropolished from a "cutoff" surface or smoothed with a fine file after sawing. For most photography, an additional grinding to 00 emery paper is done prior to final polishing.

**Operating Procedure**—The prepared specimen is clamped in place above the gasket. The leveling bottle is raised or the cell tilted until the specimen is covered by the electrolyte. The current and stirrer are switched on for 20 to 60 sec., the current switched off, and the level of electrolyte lowered. The specimen is removed, rinsed under running water and dried.

**Comparison With Mechanical Polishing**—The following tabulation compares the time required

for mechanical and electrolytic polishing. The figures given are averages for all types of specimens polished over a long period of time in the author's laboratory.

OPERATION	POLISHING TIME PER SPECIMEN	
	ELECTROLYTIC	MECHANICAL
Setup, cleaning apparatus, mixing solutions . . . . .	2 min.	2 min.
Preliminary preparation (including mounting when necessary) . . . . .	5	10
Polishing . . . . .	1	15
Total . . . . .	8 min.	27 min.

Figure 6 shows the microstructure of a piece of improperly annealed 18-8 stainless steel, electropolished from a cutoff surface. It will be noted that several areas are out of focus. For visual examination all areas are easily focused manually. Figure 7 shows a similar structure electropolished after a 00 emery preparation. All areas are in focus. One polishing mark is present across one edge; it was necessary to select the field to show this imperfection.

## CORRESPONDENCE

### Stress-Rupture Tests of 5% Chromium Steels With Molybdenum and Titanium

NIAGARA FALLS, N. Y.

To the Readers of METAL PROGRESS:

A question may well be raised about the high temperature strength of the 5% Cr (Mo + Ti) steels reported by C. L. Clark in *Metal Progress* for December last. In Fig. 12 of this article (page 1201) the line for the titanium steel is terminated at 1100° F., giving the inference that at the base of the chart, or at 1000° F., the rupture strength would be around 5000 or 6000 psi. for 100,000 hr. This of course supports Dr. Clark's statement in the text that the titanium modification has the lowest rupture strength. According to the data on p. 105 of "1946 Timken Digest of Steels for High Temperature Service", however, a value between 9000 and 10,000 psi.

is reported. If this point had been included in Fig. 12 the disparagement of the titanium steel compared with the others would be much less marked.

(Incidentally, it should be understood that data for 100,000-hr. rupture strengths are extrapolated, and therefore only approximate. Tests are very seldom continued even to 10,000 hr.)

It is unfortunate that the composition of the titanium steel is not given in Fig. 12. It is now known from the data presented by the present writer in *Transactions*, V. 36, 1946, p. 81, and derived from tests at the University of Michigan on samples from commercial heats, that the composition has an important influence on the high-temperature strength of this type of steel. If the writer's data for representative commercial analyses are extrapolated to 100,000 hr. (merely for comparison with Dr. Clark's Fig. 12) values up to about 3300 psi. are arrived at for a testing temperature of 1200° F. This compares very favorably with all



## Nominating Committee

IN ACCORDANCE with the Constitution of the American Society for Metals, President A. L. BOEGEHOLD has selected a nominating committee for the nomination of president (for one year), vice-president (for one year), treasurer (for two years) and two trustees (for two years each). This committee was selected by President BOEGEHOLD from the list of candidates submitted by the chapters. The personnel is:

A. H. D'ARCAMBAL, Pratt & Whitney Division, Niles-Bement-Pond Co. (Hartford Chapter); chairman.

FLOYD R. ANDERSON, Gardner-Denver Co. (Rocky Mountain Chapter).

W. E. BURNDRETT, Hughes Tool Co. (Texas Chapter).

R. L. DOWDELL, University of Minnesota (Northwest Chapter).

THOMAS G. HARVEY, Monarch Steel Co. (Indianapolis Chapter).

ARTHUR W. WINSTON, Dow Chemical Co. (Saginaw Valley Chapter).

R. J. RAUDEBAUGH, University of Rochester (Rochester Chapter).

S. P. WATKINS, Rustless Iron and Steel Division, American Rolling Mill Co. (Baltimore Chapter).

C. K. LOCKWOOD, Shawinigan Chemicals Ltd. (Montreal Chapter).

THIS COMMITTEE will meet during the third full week in the month of May. They will welcome suggestions for candidates in accordance with the Constitution, Article IX, Section 1 (b), which provides that endorsements of a local executive committee shall be confined to members of its local chapter, but individuals of a chapter may suggest to the nominating committee any candidates they would like to have in office. Endorsements may be sent in writing to the chairman or any member of the committee.

give titanium-carbon ratios slightly lower than are commonly encountered commercially, even higher rupture strengths are attained by this type of steel. Extrapolating again—merely for comparison with Fig. 12—values for 100,000-hr. life at 1200° F. are indicated from the writer's data for the modified compositions with between 3800 and 5000 psi. stress, which is equal to the best steel (1% Mo) in Fig. 12. Thus the author's statement and illustration on titanium 4 to 6% chromium steel do not indicate correctly or fairly what has been shown to be possible with this grade.

GEORGE F. COMSTOCK  
Chief, Physical Metallurgy  
The Titanium Alloy Mfg. Co.

### Mr. Clark Replies

Unfortunately, at the time the diagram (Fig. 12) printed last December was drawn, the rupture test data at 1000° F. quoted by Mr. Comstock were not available, and consequently were not included on the graph. It is true, as he states, that results now available, extrapolated to 100,000 hr., show a rupture strength of 9600 psi. at 1000° F. However, this stress is still below those shown for the other modifications of 5% Cr-Mo steel, and consequently the statement made in my article remains correct. While it is possible that somewhat better results may obtain for selected analyses, our tests were made on heats conforming to commercial analyses, heats which were well within these ranges. We believe this is the only correct way to appraise material in regular production.

It is of course true, as Mr. Comstock states, that the 100,000-hr. rupture strength values are based on extrapolations but the same is likewise true of any other high-temperature design values, such as creep strengths, and it is believed extrapolation of the rupture values is much less open to criticism. In this connection it might be of interest to note that the few failures of 5% Cr (Mo+Ti) tubes which have occurred in service have correlated almost exactly with the rupture data.

## Slow Changes in Hardened Steel

BRIDGEPORT, CONN.

To the Readers of METAL PROGRESS:

Whether or not you are of the type that gets timid about airline travel when the newspapers play up an unfortunate accident, a metallurgist cannot help but wonder whether structural failure has had anything to do with it. (The C.A.A. statistics show that 12% of the airplane accidents—in 1945

the other 0.5% molybdenum steels in Fig. 12, whereas Dr. Clark's graph for the titanium steels seems to lie at about the minimum of the range for commercial analyses. It would be interesting to know what the *minimum* values would be for the other steels he shows in comparison.

Furthermore, the published data referred to have shown that by modifying the composition to

— were due to structural failures.) I, therefore, wish to make a few observations and speculations.

My metallurgical experience was for many years in the heat treatment of steel. My job required me to visit many heat treating shops and qualify them as heat treating vendors for aircraft factories. The steel which we used was mostly 8620, 9315, 4620, 8630, 4130, 4340, and some others which substitute for these grades.

Anyone who has had anything to do with an airplane knows very well the most unusual shape of its steel fittings. It is common to encounter a very thin web-like section right alongside a heavy section, joined at all imaginable angles. Such parts are often machined almost to the finished size prior to heat treatment and are required, after heat treatment, to develop a minimum tensile strength of 180,000 psi. and hardness of Rockwell C-39 to 44.

Aircraft bolts, which are often made from 4340, are also heat treated to high hardnesses. Some parts made from carburizing grades require core hardnesses of C-33 to 40, and case of C-60 min.

In the heat treatment of aircraft fittings, bolts and parts, there are two factors which give heat treaters a great concern—warping and cracking. In my inspection travels from shop to shop I have noticed that it is a common practice, for the preventing of warpage or cracking, to quench steel parts not to the temperature of the oil, but to withdraw them from quench and immediately place them into the tempering furnace while they are still hot. After tempering, aircraft parts are usually sandblasted, magnafluxed and inspected for hardness on the Rockwell machine, and usually are found within the limits of required hardness.

At this point I cannot help wondering: Will hardness, microstructure and dimensions of the heat treated parts remain the same at all expected conditions which an airplane may encounter?

I regret I cannot make a positive statement in this matter, which would require a study of parts going into a certain plane, and a corresponding investigation after several thousand hours of flying. I rather express an opinion which is based on my practical experience and a few tests.

On several occasions I was called upon to investigate the failure of certain airplane parts. My first step usually was a macroexamination of the fracture, followed by a hardness check and microexamination of the specimen. I often found that the hardness was higher than specified for the part, and microexaminations revealed a mixed structure consisting of troostite and some other structure strongly resembling martensite.

Now, how did the part with higher than specified hardness pass rigid final inspection? How does one account for mixed microstructure when the part

was well tempered? To find at least a partial answer to this problem I gave some of the parts which were under investigation a subzero cold treatment, and found that sometimes the hardness of the parts increased even more. Similar conditions existed in some carburizing grades, even if parts were quenched cold to the temperature of the oil in the process of heat treatment.

To summarize it all, I have formed the opinion that many aircraft steels are sluggish on transformation, especially when not completely quenched, retaining austenite which transforms at low temperatures that are encountered by an airplane flying at high altitudes and during the winter months. Therefore, bolts or fittings which are supposed to have precalculated physical properties such as elastic limit, proof strength, and impact values, do not perform to the expectation because of unsuspected changes in the metal while in service.

VICTOR KAPPEL  
President  
Connecticut Metal Treating Co.

## Ghost

BLOOMFIELD, N. J.

To the Readers of METAL PROGRESS:

Here is a picture which may interest some of you victory gardeners and hobby farmers. This



full bloomed tulip was found in the structure of cast iron at a magnification of 200 $\times$ . It gave us a breath of spring on a cold winter's day.

MARIE H. WHITEHILL  
Works Laboratory  
Air Conditioning Dept.  
General Electric Co.

*A plea for a steady program of destructive testing on important machine parts as a method of improving design and saving money. Destructive tests on*

*forged parts for variable pitch propellers — parts rejected because of slight surface or sub-surface discontinuities — indicate that the body of the metal*

*nearly always has considerably better tensile properties than specified, and the over-all strength of the part is far greater than the maximum requirements.*

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## THE VALUE OF HIGHLY DESTRUCTIVE TESTING

By MICHAEL G. CORSON

Metallurgical and Chemical Consultant, New York City

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THERE IS AT PRESENT a tendency to substitute specialized nondestructive testing for the previously used tensile, impact and endurance tests. While the logic of that tendency is very strong it is not 100% correct. Its application apparently can be of much help to the producer of materials and parts; it tends, however, to ossify the fundamental assumptions by eliminating them from experimental reinvestigation — research, in the true sense. It is too easy to assume that, once the average characteristics of a material having a clear-cut history are well known, the checking of the finished part for deficiencies, at or near the surface, by magnetic or fluorescent examination (for example), would suffice for the acceptance of the semifinished or completed article.

I shall show in the following that this is not exactly true.

During the past few years I happened to organize a laboratory for the metallurgical testing of the materials and parts that go into the Hamilton variable pitch propellers. During that work, I frequently passed beyond the minimum of formal testing and undertook investigations which seemed quite useless to many of my technical associates with the "practical" type of mind.

An instance may be chosen from among the many parts that go into the construction of the propeller — the "spider" — which carries the greatest responsibility. It is a steel forging usually

made in the aircraft quality 4340 steel. The size to be investigated was the second largest, intended for the long-distance bombers. It has three arms, each carrying a forged blade of a duralumin type alloy. Between the bore of the blade and the outside diameter of the spider arm is a centrifugally-cast and heat treated bushing of aluminum bronze. An oil pressure mechanism permits the blade to be rotated over a given arc around the arm, in this manner changing the angle of attack.

The raw forging weighed over 80 lb.; after machining, its weight was about 35 lb., which shows how much of a costly material was reduced to comparatively worthless scrap.

Each spider was actuated by an engine developing 1700 hp. at 2700 r.p.m., so the maximum torque for each of the three arms was about 1150 ft.-lb. The corresponding stress was distributed over 8½ in. of the arm's length, and the torque mentioned corresponded to a force of 1670 lb. applied at the end of each.

Usually, even this load would not be reached in flight. But a rapid acceleration plus the vibrations resulting might, perhaps, raise it to 5000 lb. Even should the plane be diving with a speed of 600 miles per hr., and should the blades get stuck and act as plain flat surfaces instead of airfoils, the load on each arm of the spider could not go beyond 26,000 lb.

The test problem was then to determine how



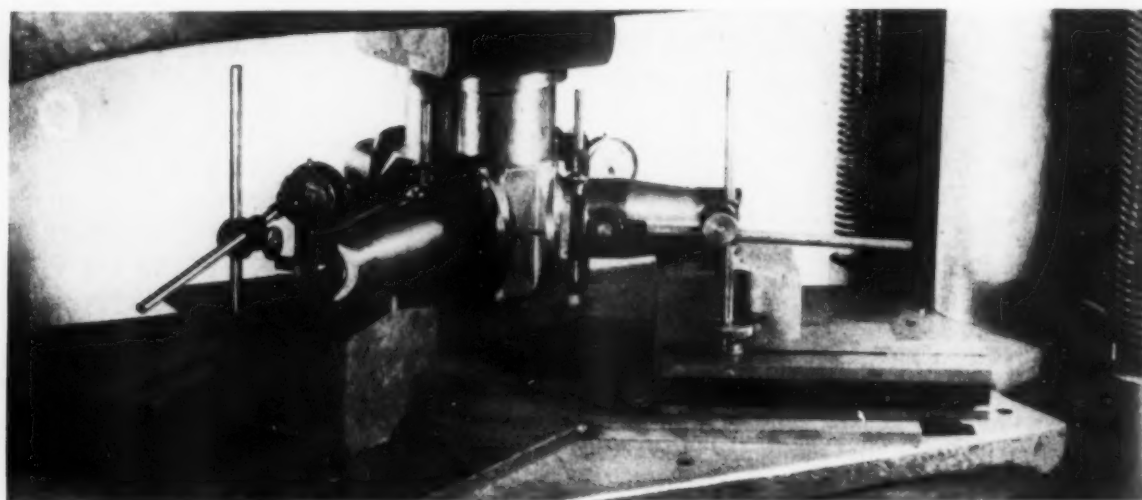
such spiders would be expected to behave in a plain static test.

This investigation was performed at my request by Prof. J. S. Peck of City College of New York. The spiders were supported on three blocks of hardened steel and the load was applied axially by a 400,000-lb. testing machine. Deflections were measured for each arm with a precision of 0.0001 in. Figure 1 shows a spider being tested, Fig. 2 a broken arm, and Fig. 3 a closer view of a similar fracture, showing three large areas of coarse cleavages.

The spiders tested had a surface hardness varying between 375 and 415 Brinell. Figure 4 shows the load-deflection curves for each arm on

Readings much above 250,000 lb. total load were usually meaningless, as the point of support was changing. However, the hardest spiders (within specification) of one particular make could be loaded to 300,000 lb., without exhibiting a nonuniform behavior in their three arms and without fracturing. But a harder spider of a different make (440 Brinell) snapped at 280,000 lb., which was fully 50% above its elastic limit. Fracture was accompanied by a large evolution of heat; the darkened room was lit up as by lightning. The fracture of that arm (Fig. 3) showed three spots in which bright areas of facets stood out from the nearly black background.

Now, what have those tests shown which the



*Fig. 1—Spider for Hamilton Variable Pitch Propeller Supported on Blocks Under Head of Testing Machine. Note gages for measuring deflection*

the softest and the hardest spider tested at City College. The important point is that a fully proportional and recoverable deflection continued up to a load of 40,000 lb. per arm for the softest and to 53,000 for the hardest (normal) spider, while in a few tests the elastic load went up to 63,000 lb. for spiders with a hardness of 440. Should (in a careful heat treatment) the hardness be kept at 388 Brinell, 100% of the acceptable spiders would undergo no permanent deformation below 46,000 lb. per arm.

The deflections measured on the arms of the individual spider were rather uniform, even during plastic deformation, which went on up to 250,000 lb. total load. To illustrate: Deflections at the elastic limit of 130,000 lb. on a typical forging were 0.0995, 0.0988, and 0.1035 in. Under a load of 230,000 the deflections were 0.2335, 0.2275, and 0.2355 in. The permanent deflection after application and release of 250,000-lb. total load: 0.123, 0.133 and 0.120 in.

specified tests for surface soundness would not show? I think they have shown plenty; to wit:

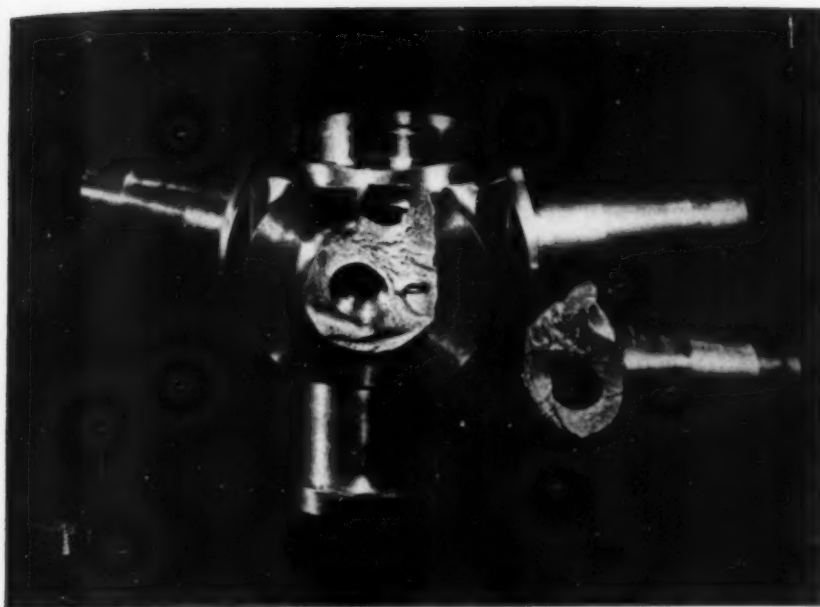
1. That even the softest spider had strength much in excess of the possible stress that could ever develop in its life of service.

2. That the forging could have been heat treated to a considerably lower hardness and still be quite satisfactory. This would mean an enormous saving in the expense and time of machining.

3. That a lower alloy steel containing less nickel and perhaps less chromium could be used.

4. That (most likely) the manufacturing method could be radically changed. A good casting, particularly a centrifugal casting, would come closer to the finished size, possess all the strength needed, and would save a considerable weight of steel turnings, millings and borings.

The original Hamilton propellers had spiders that were forged by a firm with a large amount of experience in that specific job. As I understand it, these spiders passed through no less than nine



**Fig. 2 — Fractured Arm After Test to Destruction**

forging operations. The spiders hardened most uniformly and even at 415 Brinell presented no specific machining difficulties. Rejections on magnaflux indications were exceedingly rare.

It was not so when our production began. I do not know where the trouble was—in the steel supplied or in the forging procedure. So, when I say that the forging was done in three operations instead of nine, that our spiders were difficult to machine, carried many hard spots and were frequently rejected on magnaflux indications, I do not propose to correlate all these observations. I merely state the facts.

Since magnafluxing was a part of the specifications, I had no choice but to reject many spiders (finished and worth many hundred dollars apiece) that had definite "indications". However, instead of sending all of these to the scrap pile I sent four of the worst ones to Professor Peck to be tested in a somewhat different manner, albeit using the same setup.

They were tested first for the elastic limit. Two, having a hardness of 388, had an identical elastic limit of 140,000 lb. (total load) or 47,000 lb. per arm. One, with a hardness of 352, had an elastic limit of 110,000 lb. total or 37,000 per arm—which is still away higher than the possible equivalent load under the worst conditions of operation. The worst spider (by magnaflux indications) had a hardness of 415 and an elastic load of 150,000 lb.

Next the load was increased to 110% of the elastic load and the arms were continuously reset and reloaded in reverse. The softest one withstood

100 reversals. It failed when the load was raised to 170,000 lb., 57,000 lb. per arm.

The next one stood up for 100 reversals under a load of 154,000 lb. It then failed at a total load of 167,000 lb.

The third withstood 80 reversals at 154,000 lb. but broke next when reloaded to 148,000 lb.

The fourth failed rapidly at 170,000 lb. It was the hardest one and carried the biggest magnaflux indications, while its fracture has shown considerably larger areas of bright facets. (I am so bold as to ascribe such facets to silicon or aluminum segregation.)

Now, what would those tests mean? First of all, that magnaflux indications by themselves do not make a proper basis for

the condemnation of a forged part, unless the indicated defects are most obvious. Of the four spiders broken in testing, only one—with a rather poor surface—could not be trusted to serve well. Secondly, that destructive testing resulted in the discovery of areas of facets in the fracture. Their cause must be traced. Perhaps it was inherent in the steel. Perhaps it was segregation. Perhaps it was caused by overstraining during the too rapid forging procedure—and there is much argument supporting this possibility.



**Fig. 3 — Full-Scale View of a Fractured Arm, Showing Three Large Areas of Facets**

So, I shall conclude by stating that unless destructive testing is applied frequently enough and in all manners possible, we shall not obtain the proper correlation between the mechanical stresses to be expected and the strength to be incorporated in the machine part.

### Tests on the Pistons

There is another part, apparently highly important, of the propeller which is called the "piston". It is machined from an aluminum forging of a heat aging alloy with 4.5% copper, plus manganese and silicon, but no magnesium. It also has to satisfy specifications, although I never could form any concept of the mechanical forces which it has to withstand, and so cannot state what stresses might possibly be expected.

Usually the forgings were supplied with an accompanying affidavit certifying tensile tests made on coupons taken from the same stock, but certainly never subjected to the same type or amount of forming. Wishing to find out to what extent the forgings corresponded to the reports, I sectioned a large number of such forgings—mostly pistons rejected for some surface defect—and took from each three standard test bars in the axial and one in the radial direction.

The specifications called for a tensile strength of not less than 55,000 psi., a yield point of not less than 30,000 psi. and an elongation of over 16%. The results of our tests were:

1. The chances that the ultimate tensile strength in the axial direction might be lower than the specified 55,000 psi. are nil.

2. The probability that the ultimate tensile strength might even be close to the lower limit is very slight (about 10%).

3. Fully 80% will possess an ultimate strength of 58,000 to 61,000 psi.; 10% can possess a higher ultimate strength.

4. The lower limit of the yield point specified is also too low. No test bar taken parallel to the axis showed less than 35,000 psi.

5. Fully 80% of such test bars had a yield point of 37,000 to 40,000 psi.

6. The lower limit of elongation given in the specification (16%) is too high. About 40% of test bars taken from the forging showed less than 16% elongation on fracture and a few showed only about 10% elongation (against the 22% frequently found in coupons).

7. The reason for that substantial deviation in ultimate elongation should call for further study. Is it due to the vagaries of testing or is it present in the material itself?

8. In the transverse test, fully 65% reached the specified ultimate strength, but did not go much beyond it. A few per cent may show, however, just about 50,000 psi.

9. The specified yield point of 30,000 psi. is too low even for the transverse test bars. Most showed 35,000 psi. and some went up to 37,000.

10. None of the transverse test bars showed the 16% elongation specified. The range was from 5 to 11% and the maximum frequency was between 7 and 9%.

As I stated before, I have no idea what stresses could be expected in these pistons. I do not know even which direction is the more important one. However, as long as a yield of 30,000 or even 35,000 psi. plus a hardness of 110 to 120 Brinell is satisfactory, I venture to make the following deduction:

These pistons do not need a material as expensive as the forged duralumin and there is no need to machine that heavy forging until less than 50% of useful metal remains. The same alloy, properly degasified, and properly cast, should yield an article quite as satisfactory and far less costly. An ultimate of 45,000 psi., yield of 35,000, elastic limit of 28,000 psi., and an elongation of 6% could be guaranteed.

This is another conclusion drawn from the application of a highly destructive test. It could not be derived in another manner.

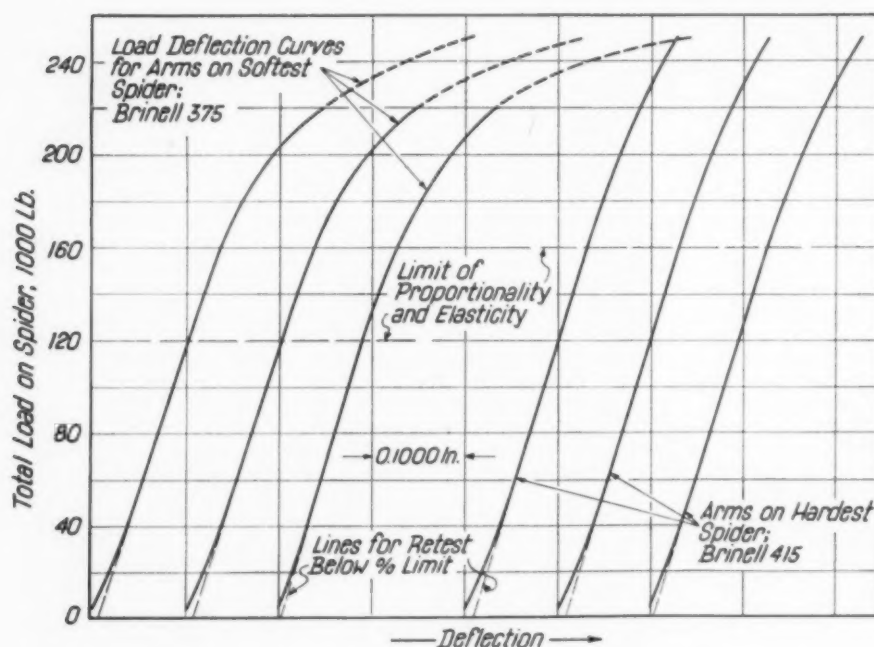
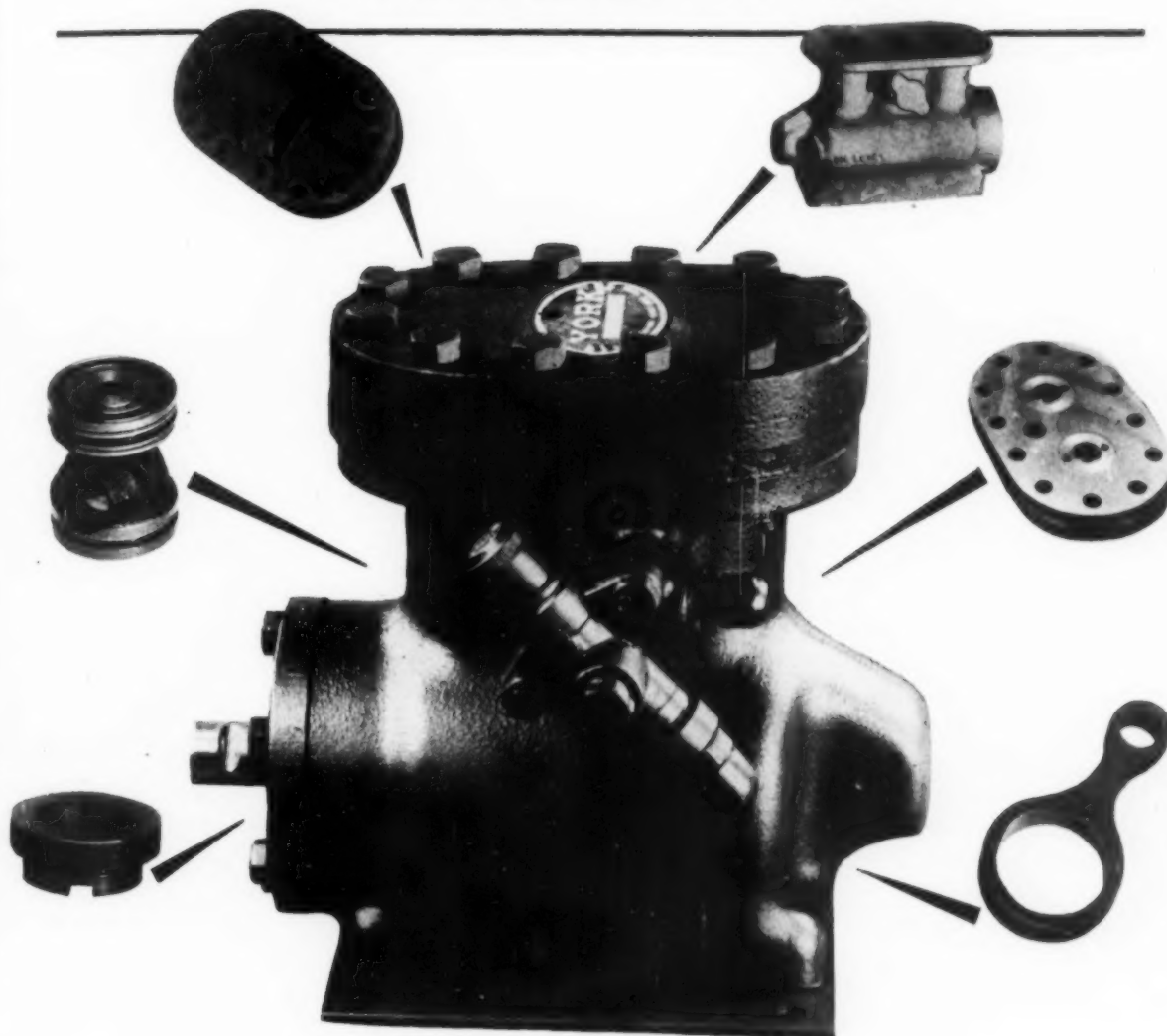


Fig. 4—Load-Deflection Curves for Each Arm of Two Spiders Tested, One a Soft Forging, One a Hard



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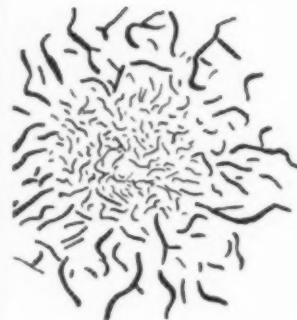
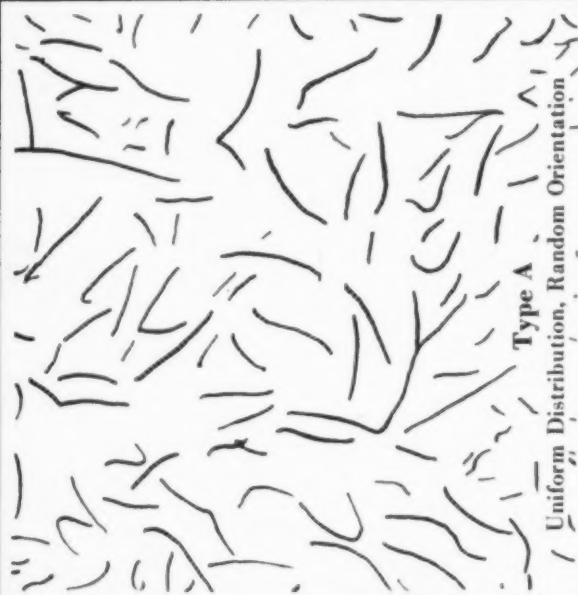


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# Graphite Flake Type in Gray Cast Iron

Recommended Jointly by American Foundrymen's Association and the American Society for Testing Materials



## Recommended Microscopic Procedure

**I**F SECTION PERMITS; a sample at least  $\frac{1}{2}$ -in. square should be polished by a technique that retains all the graphite and does not smear the metal adjacent to the flakes. Preliminary examination at  $25\times$  will determine whether more than one type of flake is present; each type should be reported, giving approximately its proportion of area, as well as the flake size number. If a consistent variation, such as surface to center, is evident, the respective location of the graphite ratings should be recorded.

Sizes may be estimated by comparing the standard charts with the image on the ground glass at  $100\times$ , or by using calibrated microscope oculars on which are engraved appropriate markings. Sizes are numbered according to the length of the longest flakes when viewed at  $100\times$ , as follows:

Size No. 1:	$> 4$ in.	Size No. 5:	$\frac{1}{4}$ to $\frac{1}{2}$ in.
No. 2:	2 to 4 in.	No. 6:	$\frac{1}{8}$ to $\frac{1}{4}$ in.
No. 3:	1 to 2 in.	No. 7:	$\frac{1}{16}$ to $\frac{1}{8}$ in.
No. 4:	$\frac{1}{2}$ to 1 in.	No. 8:	$< \frac{1}{16}$ in.

Last May *Metal Progress* printed an extended account of the properties and characteristics of the 27% chromium-irons (Type 446) under Mr. Newell's authorship. Later, in November and December, appeared articles by Claude L. Clark describing steels

containing 4 to 10% chromium, especially intended for high temperature service. The present contribution (from an address given at the Western Metal Exposition) fills the gap, at least as far as heat resisting iron-chromium alloys are concerned,

since it describes the nonhardenable commercial alloys containing from 12 to 24% chromium. These articles therefore bring up to date much of the information contained in Chapters 9 to 13 of the 1935 edition of "The Book of Stainless Steels".

## HIGH CHROMIUM-IRONS

By H. D. NEWELL\*

Chief Metallurgist, The Babcock & Wilcox Tube Co., Beaver Falls, Pa.

**H**IGH chromium-irons (or "ferritic high-chromium steels", as they are sometimes called) represent alloys in the family of stainless steels which are nonhardenable and essentially of ferritic microstructure. They are of more restricted utility and less widely used than the austenitic stainless steels. Nevertheless, although they lack the ductility of austenitic steels, are notch sensitive, and are subject to grain growth on welding or other heating to high temperature, they have found an important place in industry in both corrosion and heat resisting applications.

During 1945, 90,911 tons of wrought ferritic chromium-irons were produced. This was about one-sixth of the total stainless steel production (exclusive of castings). This category includes the A.I.S.I. types 405, 406, 430, 430-F, 442, 443 and 446. Standard composition ranges and the ingot production are given in Table I.

Type 430 (14% Cr min.) is ordinarily thought of as the leanest alloy in chromium that is truly ferritic. Type 403 (turbine quality, containing 11.5 to 13.0% Cr and 0.15% max. carbon) as well as the 13% Cr cutlery steel (Type 420) are definitely hardenable, martensitic steels. Although Type 405 (with 11.5 to 13.5%) is relatively low in chromium con-

tent, it has much smaller hardenability by virtue of its low carbon and its minor amount of aluminum. The high aluminum content of Type 406 makes it completely ferritic.

Increase of carbon in the ferritic chromium-irons will alter them to hardenable types. Nickel additions also tend in this direction by extending the so-called gamma loop (Fig. 3). Nitrogen, also an austenite former, is commonly added to the 27% chromium alloy (Type 446) for grain refinement and improvement in workability. Sulphur, selenium and molybdenum may be added in small percentages to improve machinability — as in Type

Table I—Analysis and Production of Ferritic Chromium-Irons

TYPE	CARBON (MAX.)	CHROMIUM (RANGE)	OTHERS*	INGOT TONNAGE†
405	0.08	11.5 to 13.5	Al, 0.10 to 0.30	1,579
406	0.15	12.0 to 14.0	Al, 3.5 to 4.5	1,804
430	0.12	14.0 to 18.0		82,935
430-F	0.12	14.0 to 18.0	{ P, S or Se 0.07 min.; Mo or Zr 0.60 max.	902
442	0.25	18.0 to 23.0		180
443	0.20	18.0 to 23.0	Cu, 0.90 to 1.25	338
446	0.35	23.0 to 27.0	N, 0.25 max.	3,173

\*Manganese 1.0% max., silicon 1.0% max., sulphur 0.03% max., phosphorus 0.04% max.

†A.I.S.I. statistics for 1945; tonnage of castings not included.

\*The author acknowledges the helpful assistance of his associates in the preparation of this paper, particularly from J. J. B. Rutherford, assistant chief metallurgist, and M. A. Cordovi, supervisor of the research department, The Babcock & Wilcox Tube Co.



Table II—Physical Properties of Annealed Material

PHYSICAL PROPERTIES	TYPE 405 12.5% Cr	TYPE 430 16% Cr	TYPE 430-F 16% Cr (S)	TYPE 442 20% Cr	TYPE 443 Cr-Cu
Modulus (a)	29.0	29.0	29.0	29.0	29.0
Density (b)	0.28	0.28	0.28	0.28	0.28
Resistance (c)	60	60	60	64	68
Specific heat (d)	0.11	0.11	0.11	0.11	0.11
Thermal conductivity					
at 212° F. (e)	14.4	15.1	15.1	12.5	12.5
at 932° F. (e)	16.6	15.2	15.2	14.2	—
Mean coefficient of expansion, per °F.					
32 to 212° F.	$6.0 \times 10^{-6}$	$5.0 \times 10^{-6}$	$5.0 \times 10^{-6}$	$4.9 \times 10^{-6}$	$5.3 \times 10^{-6}$
32 to 600° F.	$6.4 \times 10^{-6}$	$5.8 \times 10^{-6}$	$5.8 \times 10^{-6}$	$5.7 \times 10^{-6}$	$6.1 \times 10^{-6}$
32 to 1000° F.	$6.7 \times 10^{-6}$	$6.2 \times 10^{-6}$	$6.2 \times 10^{-6}$	$6.4 \times 10^{-6}$	$6.4 \times 10^{-6}$
32 to 1200° F.	—	$6.3 \times 10^{-6}$	$6.3 \times 10^{-6}$	$6.7 \times 10^{-6}$	$6.7 \times 10^{-6}$
32 to 1500° F.	$7.5 \times 10^{-6}$	$6.9 \times 10^{-6}$	$6.9 \times 10^{-6}$		
Melting range	2700-2790	2600-2750	2600-2750	2600-2750	2600-2700
Ferromagnetic	Yes	Yes	Yes	Yes	Yes
Thermal treatment					
Initial forging	1950-2050	1950-2050	1950-2100	1950-2050	1900-2050
Low annealing	1350-1500	1400-1500	1250-1400	1400-1500	1400-1500
Hardenability	NAH	NAH	NAH	NH	NH

(a) In tension, psi.  $\times 10^6$ .

(b) Lb. per cu.in.

(c) Specific electrical resistance at 70° F., in microhms per cm. per sq.cm.

(d) B.t.u. per lb. per °F. between 32 and 212° F.

(e) B.t.u. per hr. per sq.ft. per °F.

NAH—Not appreciably hardening.

NH —Nonhardening.

430-F—but they tend to detract from corrosion resistance and may influence other properties—particularly ductility.

### Physical and Mechanical Properties

The ferritic chromium-irons are ordinarily used in the annealed condition, particularly since they do not harden by cold work to the extent of the austenitic steels, even with such relatively severe amounts of reduction as 70% or more. Physical constants and representative mechanical properties are shown for comparison in Tables II and III. Mechanical properties of a given lot may vary within limits from the averages shown, depending on the size and form tested, and on the details of past mechanical or thermal treatment.

Type 406, containing 4% aluminum, offers good scaling resistance and is entirely ferritic, owing to the strong ferrite-forming tendency of aluminum. This grade is being used primarily for the manufacture of electrical resistor elements as it has nearly double the electrical resistance of the other

alloys (115 microhms) together with a low thermal coefficient of electrical resistance up to about 1000° F.:

75 to 600° F.: 1.2

75 to 1000° F.: 1.3

75 to 1200° F.: 1.4

Because it is not used as a general constructional material it is not further considered herein. Type 446 (27% Cr) was described in great detail by the present author in *Metal Progress* for May 1946, and, therefore, it also will be omitted in the present discussion except incidentally as a standard of reference.

Chromium ferrites, intermediate in chromium between Types 430 and 446, as exemplified by

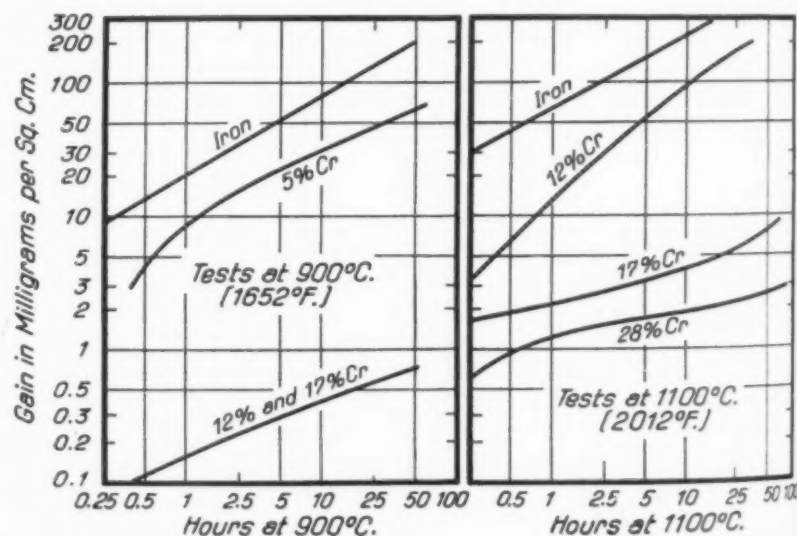


Fig. 1—Representative Curves for Time-Scaling Data Obtained by Heindlhofer and Larsen for Chromium-Iron Alloys at 900 and 1100° C. (Respectively 1650 and 2010° F.)

Types 442 and 443 with about 20% Cr, are intermediate also in respect to corrosion and heat resistance and have been adapted to particular uses where they will perform economically. Addition of copper, which is a weak austenite former, does not modify the structural characteristics of Type 443 from those found in Type 442. According to J. H. Parker in "The Book of Stainless Steels", the cop-

per addition improves resistance to corrosion in certain media, making the alloy immune to certain foodstuffs and organic acids. Its resistance is also good in mixed acids such as are used in nitrocellulose plants, in explosives and rayon manufacture. Type 442 has also been used in such applications, and both alloys have served where scaling resistance is required, as in furnace parts, annealing trays, stirring rods for molten brass and copper, and as soot blower elements. As may be noted from the production figures in Table I, neither of these alloys is used in quantity.

**Scaling Resistance** — These alloys resist oxidizing corrosion excellently at ordinary temperature, and likewise have relatively high resistance to scal-

ing at elevated temperatures. This is somewhat proportioned to chromium content although the true scaling rate varies with atmosphere and temperature. Thin oxide films are formed at low temperature; thick, visible films form at higher, where sulphur and oxygen are the principal scaling agents. However, reducing conditions, cyclic variations in temperature, or frequent changes from oxidizing to reducing circumstances may be damaging. Heindlhofer and Larsen have described the mechanism of scaling on iron and certain alloys in "The Book of Stainless Steels" while Rickett and Wood (*Transactions* ②, 1934) have studied the action of hydrogen sulphide and find that chromium has little protective action. Some of the data are plotted

in Fig. 1 and 2 (pages 618 and 620). Tests by others indicate that the scaling rate may be altered at a given temperature, depending on the composition of the furnace gases in contact with the metal.

Industrially, the several ferritic chromium-irons are considered to be resistant in normal applications without excessive scaling up to the following temperatures:

Type 405 (12 Cr): 1300° F.  
Type 430 (17 Cr): 1550° F.  
Type 442 (21 Cr): 1750° F.  
Type 446 (27 Cr): 2000° F.

### Structural Features

The constitution of iron-chromium alloys has been studied by many investigators and the constitution diagram published frequently (see page 986, *Metal Progress* for May 1946). The principal characteristic is that the range of temperature wherein gamma iron (austenite) exists is contracted by increasing amounts of chromium. In carbon-free iron, for example, alpha iron transforms to gamma iron when heated past 1670° F., and reverses the

Table III — Tensile Properties of Ferritic Stainless Irons

FORM AND TREATMENT	ULTIMATE STRENGTH	YIELD STRENGTH*	ELON- GATION† IN 2 IN.	REDUC- TION OF AREA	HARDNESS	
					BRINELL	ROCKWELL
Type 405 (12.5% Cr)						
Sheet, annealed	65,000	40,000	25.0	—	—	B-70
Bars, annealed	70,000	45,000	35.0	60.0	160	—
Tubing, annealed	75,000	45,000	40.0	—	165	—
Type 430 (16% Cr)						
Sheet, annealed	75,000	45,000	25.0	—	—	B-80
Strip, annealed	75,000	45,000	25.0	—	—	B-80
cold rolled	100,000	—	8.0	—	—	B-98
Wire, annealed	70,000	40,000	35.0	—	—	B-82
cold drawn 20%	90,000	—	13.0	—	—	B-93
40%	100,000	—	10.0	—	—	B-98
60%	110,000	—	8.0	—	—	C-23
Plate, annealed	75,000	40,000	35.0	60.0	160	—
Bars, annealed	75,000	40,000	35.0	60.0	160	—
cold drawn, 20%	92,000	—	15.0	45.0	190	—
Forgings, annealed	75,000	40,000	35.0	60.0	160	—
Tubing, annealed	75,000	40,000	30.0	—	—	B-82
Type 430-F (16% + S)						
Bars, annealed	85,000	50,000	25.0	50.0	170	—
cold drawn	105,000	—	15.0	45.0	207	—
Forgings, annealed	85,000	50,000	25.0	50.0	170	—
Type 442 (20% Cr)						
Sheet, annealed	80,000	45,000	20.0	—	—	—
Strip, annealed	80,000	45,000	20.0	—	—	—
Wire, annealed	80,000	45,000	20.0	—	—	B-85
cold drawn 20%	105,000	95,000	15.0	—	—	B-95
40%	120,000	110,000	10.0	—	—	B-99
60%	135,000	120,000	5.0	—	—	B-101
Plate, annealed	85,000	45,000	20.0	50.0	175	—
Bars, annealed	85,000	45,000	20.0	50.0	175	—
Forgings, annealed	85,000	45,000	20.0	50.0	175	—
Type 443 (20% Cr + Cu)						
Sheet, annealed	85,000	60,000	20.0	—	—	B-85
Strip, annealed	85,000	60,000	20.0	—	—	B-85
Plate, annealed	90,000	50,000	20.0	55.0	187	—
Bars, annealed	90,000	50,000	20.0	55.0	187	—
Forgings, annealed	90,000	50,000	20.0	55.0	187	—

\*Stress at 0.2% offset.

†Elongation values vary with thickness or diameter, being higher with larger diameters or greater thickness.

change at high temperature (2550° F.) becoming "delta" iron, indistinguishable crystallographically from alpha iron.

If chromium is added to iron, the upper temperature where gamma changes to delta iron is reduced sharply, so that the range of temperature wherein austenite can form is restricted. In fact, the combined raising of the  $\alpha \rightarrow \gamma$  transformation and the lowering of the  $\gamma \rightarrow \Delta$  transformation is enough to extinguish the austenite entirely in carbon-free alloys containing 14% chromium or more — "closes the loop" as it were. Since quench-hardening of steel depends on the transformation of austenite on cooling, the high chromium-irons — having no austenite at any temperature — are incapable of hardening by heat treatment.

Carbon is the principal element that affects the location of the austenitic loop described above, and sketched in Fig. 3. As may be noted, the gamma loop has no sharp line of demarcation, there being a small boundary field of mixed phase alloys (austenite and ferrite). Aluminum has a ferrite-forming tendency of about 10 to 1 over chromium; this implies that the minor aluminum addition in Type 405 amounts, in effect, to a 2% chromium increase,

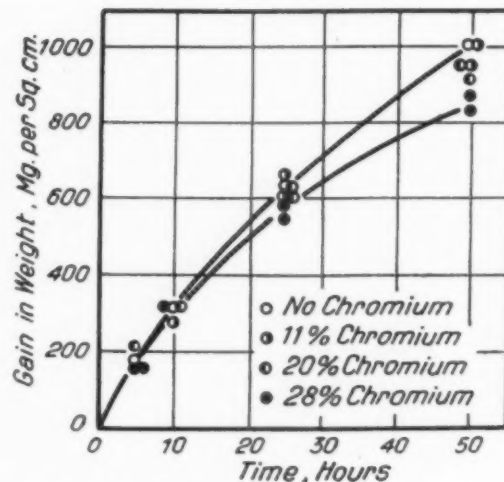


Fig. 2 — Relation Between Time and Gain in Weight (Amount of Scaling) in a Series of Chromium-Iron Alloys in Hydrogen Sulphide Gas at 1800° F. (Rickett and Wood)

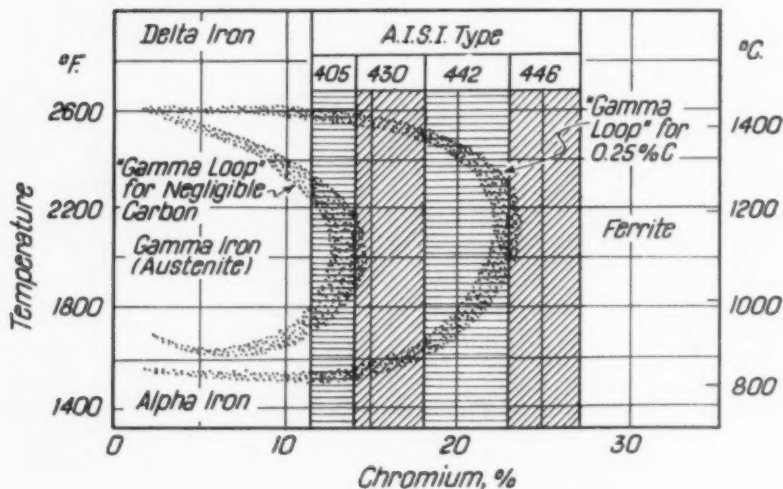
are nonhardenable or only faintly hardenable at best. The carbide existing is, of course, increasingly soluble in the metal matrix (ferrite) with increased temperature; there may even be a little stable austenite formed sluggishly at a sufficiently elevated temperature in the vicinity of the carbides. Grain growth of the ferrite naturally occurs at sufficiently elevated temperatures.

Typical structures of the 12% and the 17% chromium-irons both in the quenched and fully annealed condition are shown in Fig. 4 and 5. Comparison of these quenched structures with those of the 27% Cr-Fe alloy given in *Metal Progress* last May would imply somewhat greater austenite formation in Types 405 and 430 than in the higher chromium alloys. The exact result will depend on specific composition — particularly with respect to carbon, nitrogen and chromium, and aluminum in Type 405. As would be expected, Types 442 and 443 (18 to 23% Cr) assume an intermediate position.

The influence of chromium content on hardening may be noted by reference to the quenching tests depicted in Fig. 6.

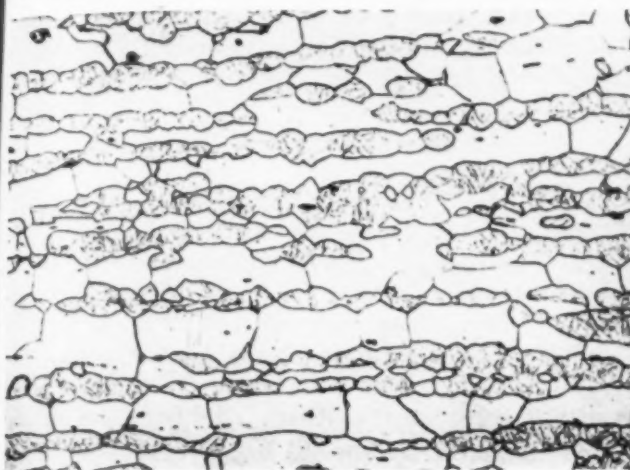
All of these ferritic steels exhibit a coarse grain in the cast state, are tender and somewhat difficult to work, and may crack from thermal shock if heavy sections are cooled to ordinary temperature. Hence, they are best worked from the hot ingot, with appropriate reheating and with finishing temperatures well down in order to refine the grain through

Fig. 3 — Loop Diagram Showing Influence of Carbon Content on the Austenitic Field, and the Relative Position of Commercial Ferritic Alloys

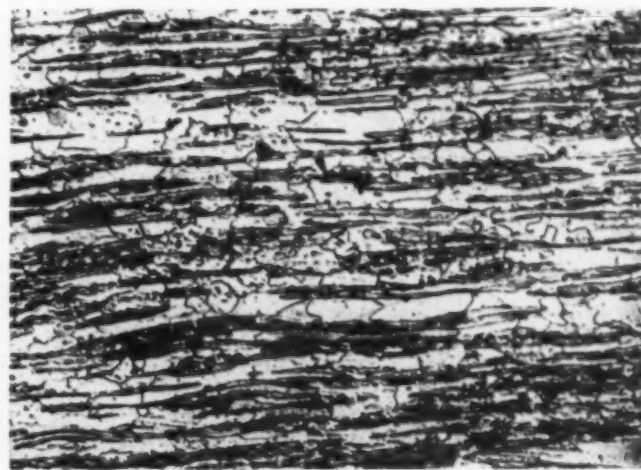




Water quenched from 2000° F., hardness 183 Brinell



Annealed at 1400° F., air cooled, hardness 133 Brinell



**Fig. 4 — Type 405 Nonhardening Chromium-Iron (12% Cr + Al), Etched With Mixture of Hydrochloric and Picric Acids, 100 ×**

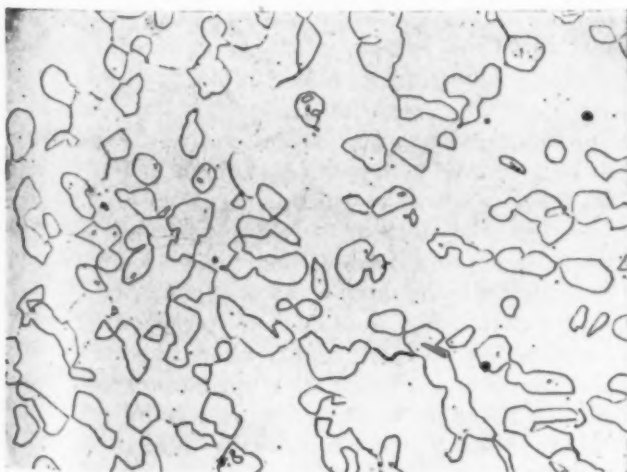
mechanical work. The 12% chromium Type 405 alloy is least subject to excessive grain growth on heating to high temperature, because its partial transformation to austenite restricts growth. The purposeful addition of nitrogen to the 27% chromium grade, as originated by Russell Franks, is also useful in restricting growth and providing better working properties, as well as tending to prevent growth during high temperature service.

Similarity of the ferritic chromium-irons in respect to structural features, notch sensitivity, embrittlement on aging at 885° F., and working properties, enables us to consider these alloys as a group. Methods of working as regards forging and rolling temperatures, both initial and final, are quite similar, as are the annealing temperatures.

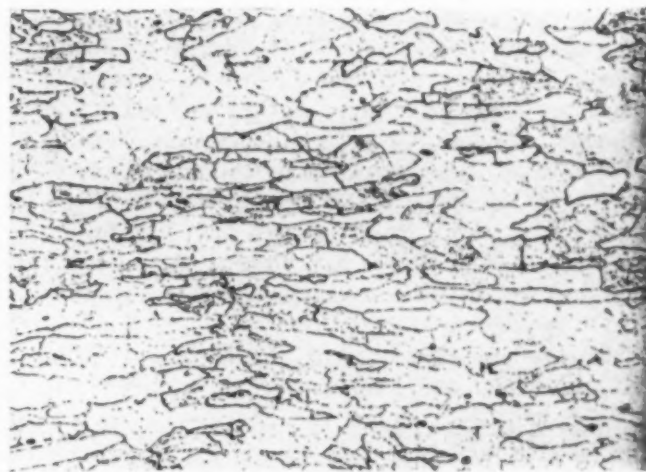
Hot working is usually done between 2100 and 1900° F., with finishing operations down to between 1300 and 1600° F., depending on the section or article being handled. Sheets and strip ordinarily are finished somewhat lower than bars and plates; tubing is intermediate.

Annealing is generally performed between 1400 and 1650° F.; grades containing more than 20% Cr are water quenched; air cooling after annealing is satisfactory for the other alloys. This distinction in annealing practice is due to the fact that the higher chromium-irons are more susceptible to 885° F. brittleness, and quick cooling through the range from 1100 to 700° F. is desirable to avoid incipient embrittlement. This practice of quick cooling was developed originally by Becket and MacQuigg;

Water quenched from 2000° F., hardness 207 Brinell



Annealed at 1500° F., air cooled, hardness 153 Brinell



**Fig. 5 — Type 430 (17% Cr-Fe) Etched in Aqua Regia, 100 ×**

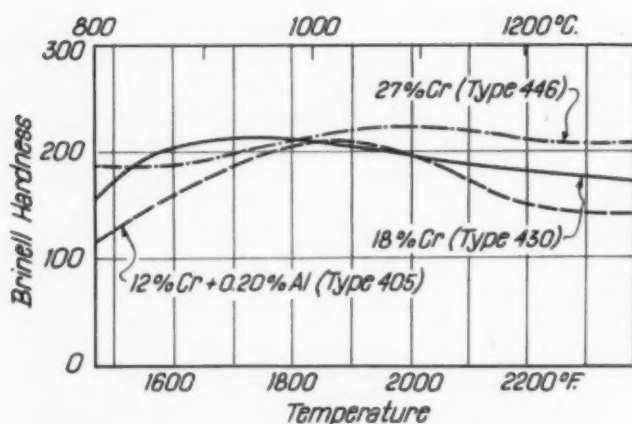


Fig. 6 — Relative Hardening of Ferritic Chromium-Irons After Water Quenching From Indicated Temperatures

British practice on high chromium-iron with nitrogen appears to differ, in that Colbeck and Garner\* advocate quenching from temperatures between 1920 and 2200° F. so as to obtain an austenite-ferrite structure rather than a mixture of ferrite and carbides.

With increasing chromium content, the annealed alloys become somewhat stiffer and less ductile, and their ability to withstand forming, spinning, stamping and such operations is reduced. Thus, Types 405 and 430 (12 and 17% Cr) are considerably better in this respect than the higher alloys. Type 430-F (17% Cr plus P, S or Se and 0.60% max. Mo or Zr) is used principally in the manufacture of machined parts from bars and forgings, and its somewhat lower ductility as compared to the regular 17% Cr grade provides for more ready machinability.

### Sigma Phase

An intermetallic compound probably containing one atom of iron and one of chromium forms in high chromium-iron alloys when held for considerable time in the range of 1000 to 1300° F. It apparently dissociates and goes into solid solution at 1500° F. and higher. Its occurrence and microscopic appearance in the 27% Cr-Fe Type 446 was presented at some length in the article in *Metal Progress* for May 1946, which may be reread to get a picture of its relationship to the more common 875° F. embrittlement.

Presence of sigma phase in alloys containing 22% chromium and less has not been reported in

\*E. W. Colbeck and R. P. Garner, "The Effect of Nitrogen Additions and Heat Treatment on the Properties of High Chromium Steels", *Journal of the Iron and Steel Institute*, V. 139, p. 99.

the literature. However, the effect of very long heating on Types 442 and 443 (18 to 23% Cr) in the 1000 to 1300° F. range has not been evaluated, as far as the present author is aware. There are theoretical grounds for expecting its appearance.

### Embrittlement at 885° F.

Prolonged heating in the range of about 700 to about 1000° F. causes age hardening and drastic loss of ductile properties of chromium-iron alloys containing more than about 15.5% chromium. This phenomenon is generally referred to as the 885° F. or 475° C. embrittlement because peak hardness on aging occurs at that temperature. Becket stated in 1938 that such embrittlement did not occur below about 20% chromium, but his heating times were not long enough. Krivobok had shown earlier that chromium-iron alloys free of carbon will age

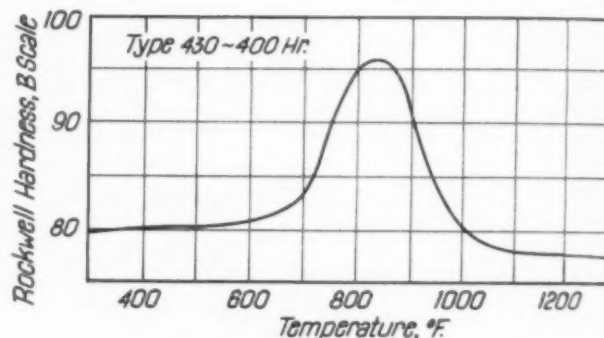


Fig. 7 — Hardness Along Temperature-Gradient Bar Heated 400 Hr. Type 430; 0.07 C, 0.33 Mn, 0.020 S, 0.019 P, 1.00 Si, 16.96 Cr

harden and that the intensity is directly proportional to chromium concentration; alloys containing 13 to 15% chromium showed but little tendency to harden as contrasted to those containing higher chromium. It is evident that the lower chromium ferritic alloys age more slowly and require more prolonged heating to bring about the changes in mechanical properties.

Shortly after 17% chromium-iron tubing began to be produced commercially (about 1925) some of it was installed in steam superheater elements working at about 900° F. Soon it became apparent that these tubes were losing their toughness. In investigating the matter at that time, the writer found that aging would occur irrespective of any combination of initial heat treatment and grain size, and that gradual increase in hardness would occur on extending the heating time to a point where the tubing became mechanically fragile at ordinary temperature — and even at somewhat elevated temperatures. Tubes were breaking under shock, and

only special precautions prevented excessive replacements. Use of the alloy, now known as Type 430, in that particular range of temperature was discontinued, even though relief from embrittlement could be temporarily accomplished by heating to 1050° F. or higher. In fairness it may be said that a number of superheaters equipped with such tubes gave good performance when carefully handled, and at least one is in operation after 20 years.

It seems proper to present certain unpublished data from these early tests (1927). Figure 7 is a typical hardness-temperature curve for Type 430 material obtained on a temperature-gradient bar. Maximum hardness closely corresponds to the accepted 475° C. (885° F.) peak aging temperature.

Twelve tensile test pieces and 12 Charpy specimens (10x10 mm. with keyhole notch) were machined from a single rod whose analysis was 0.07% C, 0.33 Mn, 0.020 S, 0.019 P, 1.0 Si and 16.96 Cr (the same as the temperature-gradient bar). These were all annealed 4 hr. at 1500° F., and cooled in still air. Half of them were then tested. The remainder were aged 400 hr. at 900° before testing. These mechanical property changes occurring on aging 400 hr. at 900° F. are somewhat surprising in view of the moderate alteration in hardness. No

Table IV — 1927 Tests on Age Hardening of Chromium-Iron Alloys\*

COMPOSITION					HARDNESS† AFTER HEATING AT 900° F.					
C	Mn	Si	Cr	Ni	0	100 Hr.	200 Hr.	300 Hr.	400 Hr.	600 Hr.
0.10	0.49	0.46	12.68	0.17	72.7	71.6	—	72.4	—	73.9‡
0.12	0.34	0.32	15.34	0.06	83.6	82.2	83.5	—	83.6	83.4
0.17	0.35	0.81	16.42	0.69	86.3	87.5	87.6	—	90.6	—
0.17	0.39	0.68	17.13	0.06	84.3	87.2	88.9	—	91.0	—
0.18	0.37	0.68	17.55	0.06	85.1	87.9	88.3	—	—	—
0.08	0.26	1.08	18.04	0.05	81.6	91.0	92.2	—	95.6	—
0.06	0.28	0.82	19.40	tr.	76.4	85.0	94.2	—	94.8	—
0.12	0.69	0.49	23.69	0.32	88.8	—	102.4	—	—	106.8
0.14	1.90	0.38	26.55	nil	83.4	92.6	99.4	102.3	103.8	—
0.09	0.40	0.23	27.56	tr.	85.4	99.6	101.3	—	105.4	—

\*Alloys annealed prior to heating.

†Rockwell B-scale hardness values; average of 10 tests on each sample.

‡This figure after 800 hr.

very discernible changes in microstructure occurred except perhaps a slight widening of grain boundaries with some mottling of the ferrite. This same change in structure on aging occurs in the higher chromium steels to a somewhat more marked extent; it is well shown in Fig. 8 in a 27% Cr-Fe alloy. Results follow:

	ANNEALED	ANNEALED AND AGED
Ultimate strength	67,500 to 68,150	79,350 to 84,800
Yield point	42,200 to 44,500	70,000 to 79,800
Elongation in 2 in.	36.0 to 37.5	2.3 max.
Reduction of area	70.0 to 71.5	0.8 to 1.8
Rockwell hardness	B-78 to 80	B-91 to 94
Charpy impact	1.2 to 1.8	0.0 to 0.5

Additional aging tests on a variety of chromium steels made at that time showed hardness increases when chromium content exceeded 15.5% (see Table IV). The validity of these tests was confirmed at a much later date by Riedrich and Loib, in a German publication in 1941, who ran age-hardening tests on a series of low carbon steels containing from 14.54 to 28.70% chromium. Their data indicate that hardening is a function of chromium content in alloys containing over about 15% chromium. Since the bulk of the hardening in the 16 and 17% Cr alloys occurred between 500 and 1000 hr., the necessity of prolonging the heating time to evaluate such aging is apparent.

Riedrich and Loib's annealed alloys at the start were all about 145 Brinell. Hardness after 1000 hr. at 890° F. was as follows:

ANALYSIS	AGED HARDNESS	ANALYSIS	AGED HARDNESS
14.5% Cr	150	20.1% Cr	260
15.9	195	21.9	270
17.0	223	23.7	290
19.4	252	28.7	320

It is noteworthy that Type 446, with its 27% chromium, hardens more on aging than Type 430 (16%) and the change in properties occurs

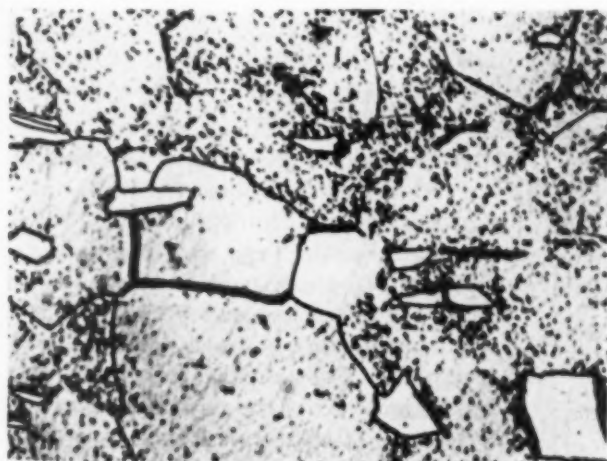


Fig. 8 — Grain Boundary Widening and Fine Precipitate Within the Grains of 27% Cr-Fe After Heating in the 885° F. Embrittlement Range. Gross carbides are also visible. Etched with aqua regia; 1000X



sooner, yet heating for as long as 13,000 hr. at 885° F. fails to cause overaging or softening. Some lattice distortion occurs, but thus far X-ray diffraction has failed to show that any sigma phase forms at 885° F., although it forms in 27% Cr-Fe at a higher temperature (1000° F.) in annealed metal, and at a somewhat lower temperature in cold worked metal. There is a distinct volume contraction during the 885° F. embrittlement, as well as the microscopic evidence of Fig. 8.

The 885° F. embrittlement phenomenon appears to be related to sigma formation, and may be an initial lattice change or distortion which leads to gross precipitation of the sigma phase when the atomic mobility is increased at but slightly higher temperature. (The internal strain imparted to annealed metal by aging is sometimes manifested in the 27% Cr alloy by automatic generation of Neumann bands or mechanical twins in the structure.) Once the mechanical properties are altered by aging, there is no recovery of ductile properties until the embrittled metal is warmed to 400° F. or higher. Partial recovery occurs at higher temperatures and return to the fully annealed state occurs on heating for a short time at 1100° F. An extended table giving the properties of embrittled 27% Cr-Fe after heating for 1 to 1000 hr. at 950 to 1200° F. is given in *Metal Progress* for May 1946, page 994.

Although specially prepared relatively pure alloys did not develop the FeCr compound on heating in the sigma range for 1500 hr., they did show the usual 885° F. aging. A 25.2% chromium alloy increased in Vickers pyramid hardness from 176 as annealed to 346 after 1000 hr. at 885° F. Simultaneously, commercial heats of 446 grade increased from an average of 181 to 356 Vickers. A special heat containing 25.58% chromium and 3.8% molybdenum exhibited even greater hard-

ness increase, aging from an annealed hardness of 218 to 402. Vacuum annealing of one of the special heats for four days at 2500° F. reduced the carbon to 0.02% and nitrogen to 0.004%, but even so, the hardness rose to 301, somewhat less than the companion metal; the lower final hardness of the vacuum-treated metal may have been due to its coarse grain size.

The purest binary iron-chromium alloys therefore show this characteristic aging as do all the commercial iron-chromium alloys containing sufficient chromium content, as well as those to which such elements as aluminum, vanadium, tungsten, molybdenum, columbium, titanium, manganese or silicon have been added. There does not appear to be any means by which such 885° F. aging can be eliminated.

### Embrittlement of Type 405 With Al

Previous investigations have failed to disclose that annealed stainless steels containing below about 15% chromium will develop 885° F. brittleness. However, a recent report from a prominent oil company cites the embrittlement and failure of the lining of a hot oil separator. The lining in this tower had been in service for five years at a temperature of about 735° F., hence within the embrittlement range, and appears to have increased in hardness from about B-75 to B-95. As some of the Type 405 strip (13% Cr plus Al) composing the lining had been welded to regular Type 410 stainless strip (13% Cr, 0.15% max. C), the nonhardening grade could be compared with the regular hardening grade of the same approximate chromium content. The latter was still ductile after exactly the same service, whereas the Type 405 strip was badly embrittled. Chemical compositions were:

TYPE	C	Cr	Al	CONDITION
405	0.08	13.18	0.18	Brittle
410	0.07	12.94	Nil	Ductile

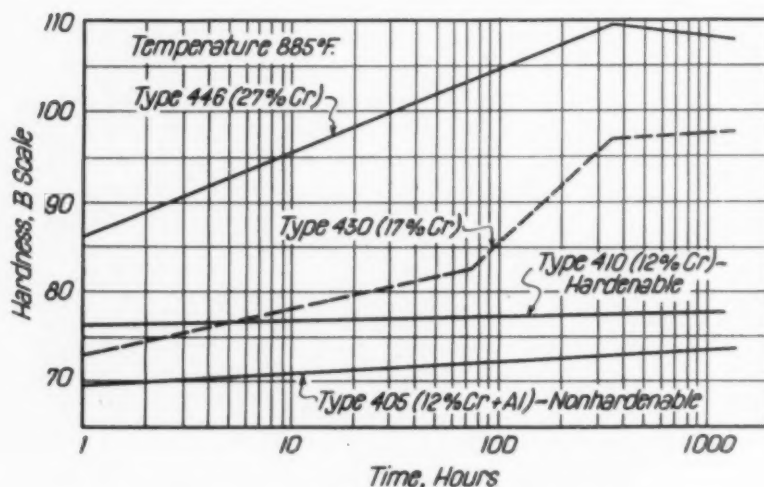


Fig. 9 — Age Hardening Tendencies at 885° F. of 12, 17 and 27% Cr-Fe Alloys

Microscopically, the embrittled sample showed some alumina inclusions, a slightly coarser grain size (No. 3 to 4) than the ductile Type 410 (No. 5 to 6). Carbides were well spheroidized in both materials and there was perhaps a slight widening of grain boundaries or boundary precipitate characteristic of 885° F. embrittlement in the brittle alloy. The brittleness could be alleviated by the usual heating above 1100° F.; a short heating at 1200° F. reduced the hardness to B-70 and restored ductility.

It would seem that the minor aluminum addition in Type 405 stainless iron acted as additional chromium in the iron

lattice and, in consequence, aging occurred on very prolonged heating. A laboratory aging test recently initiated to gain further proof of embrittlement in this low chromium ferritic alloy has failed to show appreciable hardening after heating 1500 hr. The data accumulated to date are given in Fig. 9, along with results on other grades.

### Other Properties

The ferritic iron-chromium alloys are quite notch sensitive. This characteristic appears to be directly related to the chromium rather than to carbon content or grain size. Experimental results reported by Krivobok in *Transactions*, V. 23, 1935, p. 1, show that standard Charpy specimens have unchanged toughness (90 to 120 ft-lb., irrespective of carbon content between 0.01 and 0.20) until chromium content reaches 15%, but then all drop precipitously to 10 ft-lb. or less at 18 or 19% Cr. These figures represent room temperature toughness of annealed (not aged) samples.

His investigation also indicated that transition from a brittle to a tough condition occurs in all high chromium alloys when tested at moderately increasing temperature. In other words, the chromium-iron alloys of 18 to 22% Cr, which are brittle even at best when at room temperature, have good toughness at working temperatures when below 700° F. (and also when above 1000° F., the embrittling range). To regain reasonable toughness after embrittling by heat, the alloys must be warmed to higher temperatures than would be necessary for the annealed (not aged) material. Riedrich and Loib, for example, show that an alloy having 23.7% Cr and 0.10% C had notch toughness of less than 1.0 in either annealed or embrittled condition when tested at 70° F. The annealed metal jumped to a toughness of 21 or 22 when tested at 300° F. or hotter, whereas the embrittled alloy gained toughness but slowly with temperature:

TESTING TEMPERATURE	NOTCH TOUGHNESS
425° F.	1.5
900	6.5
1475	20.0

Impact figures of considerable magnitude may be had on unnotched bars of chromium-iron alloys at room temperature; these figures drop off gradually with increasing temperature, being about half as much at about 1600° F. Notching reduces the impact strength of the 18% Cr and higher alloys to very low figures; as noted above, increasing temperature improves these figures materially to where they are about equal to the unnotched value at 1600° F. (See Fig. 10 in last May's article in *Metal Progress* for specific

values of 27% Cr-Fe.) All these grades of ferritic chromium-irons have relatively poor notch-impact strength, with the exception of Type 405 (12% Cr + Al). Some tests on this last mentioned alloy by Allegheny Ludlum Steel Corp. show Charpy values of from 17 to 60 ft-lb. at -25° F. depending on condition of material, whether hot rolled or annealed.

Notch sensitivity is a factor of major importance and should be carefully considered in the application of these ferritic steels. Good engineering practice suggests avoiding surface marks, re-entrant angles, notches or other forms of stress-raisers when the metal is used under conditions of shock loading. Design should take into account this feature and provide generous radii and smooth contours.

As regards high temperature strength, the ferritic materials, albeit superior to the majority of ordinary steels, are nevertheless much weaker than austenitic stainless steels. Being ferritic, the chromium-irons are capable of considerably greater elongation under stress when hot, and are superior in this respect to the austenitic steels in that they do not tend to break "short".

The creep strength properties of several of the ferritic chromium-irons, as recently compiled for the forthcoming edition of "Metals Handbook", are given in Table V.

### Resume of Applications\*

Perhaps too much emphasis has been placed herein on the embrittlement phenomena, to which the ferritic chromium-irons are subject under certain thermal environments. However, as they are considered to be heat resisting alloys, a knowledge of their behavior in such respects is requisite for successful utilization. Concerning sigma phase pre-

\*Thanks are due R. B. Lincoln of Allegheny Ludlum Steel Corp. for much information as to industrial usage.

Table V—Creep Strength of Ferritic Chromium-Irons

TYPE	1000° F.	1100° F.	1200° F.	1300° F.	1400° F.	1500° F.
Stress for 1% in 10,000 Hr.						
405*	8,250	3,375	1,500	975	—	—
430	8,500	5,000	2,200	1,200	800	—
442	8,500	5,000	1,600	1,000	—	600
446	6,000	3,000	1,500	600	300	—
Stress for 1% in 100,000 Hr.						
405*	7,500	2,775	975	600	—	—
430	7,000	4,500	1,600	900	—	—
446	4,200	2,300	1,000	250	100	—

\*"Allegheny Ludlum Blue Sheet" states that Type 405 has creep resistance equal to 75% of Type 410 stainless steel (12% Cr without aluminum).

cipitation, this phase change is of significance only where the 27% chromium grade is used at temperatures of about 950 to 1300° F. Except for special application, as in the dehydrogenation process, this is below usual service temperatures when this alloy is employed as a heat resisting material.

**Type 405** stainless iron (12% Cr plus 0.20 Al) was developed primarily to be used in the manufacture of stationary blades for steam turbines. These blades are inserted in the sand mold, and cast iron or cast steel poured around them. This is a nonhardening grade and does not undergo appreciable transformation and for that reason has no sudden volume change during cooling.

It is suitable for applications where the properties of a 12% chromium steel (Type 410) are desirable but in which the latter's characteristic of hardening upon cooling from high temperatures is objectionable. It is used to some extent in annealing boxes, quenching racks, and oxidation resistant partitions. The principal objection to Type 405 is the fact that when heated to temperatures over 1800° F. it forms a coarse-grained structure with small amounts of austenite at the grain boundaries; although it does not undergo any sudden volume change during cooling, and conventional hardness testing methods do not detect any marked increase in hardness, the material has very low ductility after cooling from temperatures over 1800° F. If the material after such a treatment is tempered in the range from 1200 to 1400° F. it shows good ductility in spite of its coarse grain.

Aside from its use as cast-in stationary turbine blades, Type 405 stainless iron has been used to some extent in welded constructions, as in corrosion resisting linings in vessels used in oil refineries and in chemical processes. It has also been used as heat-exchanger tubing in oil refineries where the surroundings were not so corrosive as to require metal with higher chromium. Considerable tubing of the alloy has been used in the Houdry catalytic oil cracking process, where alloy fins were welded to the tubing. The alloy was selected for such service because of its corrosion resistance toward hot oil vapors and reduced hardenability on welding. This grade has been used recently as boiler tubing in the mercury heat cycle.

**Type 430**—This popular chromium-iron alloy (14 to 18% Cr) is by far the most important of the group in tonnage. It is used in greatest quantity in strip form for trim and molding on automobiles, in which application the alloy has sufficient ductility for forming these simple parts and good corrosion resistance against weathering. Furthermore, it can be quickly polished or buffed to a pleasing finish. In a similar category, the alloy is used in wire form for manufacture of refrigerator trays,

screws for refrigeration and automobiles, as trim on household appliances, and as interior trim in buildings. It is also used in manufacture of kitchen tools and to some extent as handles on flatware.

It enjoys considerable usage in the chemical and process field because it resists corrosion by a wide variety of media. Perhaps of greatest importance among these is its extended use in towers, heat-exchange equipment, condensers and piping in the production, transportation and storage of nitric acid. It is also used in nitrating operations involving mixed acids in the form of nitrators, vessels, tanks and piping both in riveted and welded construction. Where welding is done, it is usual to restrict chromium to 16.5% to minimize grain growth in the heat affected areas. Application is also made in furnace parts, retorts and heat resisting parts subject to low stresses at service temperatures up to 1550° F.

**Type 430-F** is principally used for miscellaneous small parts made by machining. The increase in chromium content over that of Type 416 (12% Cr) stainless steel adds considerably to the machinability. It can be used for any machined part where Type 416 would be satisfactory without hardening, and where improved machinability is desired. Its corrosion resistance is approximately that of regular Type 430 in most services, and it may be more readily turned, threaded, drilled or cut. The machinability index of Type 430-F alloy is raised to about 85% of bessemer screw stock as contrasted to speeds of about 55% for the plain Type 430.

**Types 442 and 443**—These intermediate chromium-irons (18 to 23%) enjoy only limited utility in certain heat resisting applications as in rabble bars and ladles for nonferrous metals, furnace parts, heat recuperators, and as soot blower elements. Use by the chemical industry in nitrating equipment is declining in preference to stabilized austenitic chromium-nickel steels which are more readily weldable and are not subject to loss of ductility on welding. While possessing intermediate properties of oxidation and corrosion resistance between Types 430 and 446, neither of these intermediate grades is now commercially important.

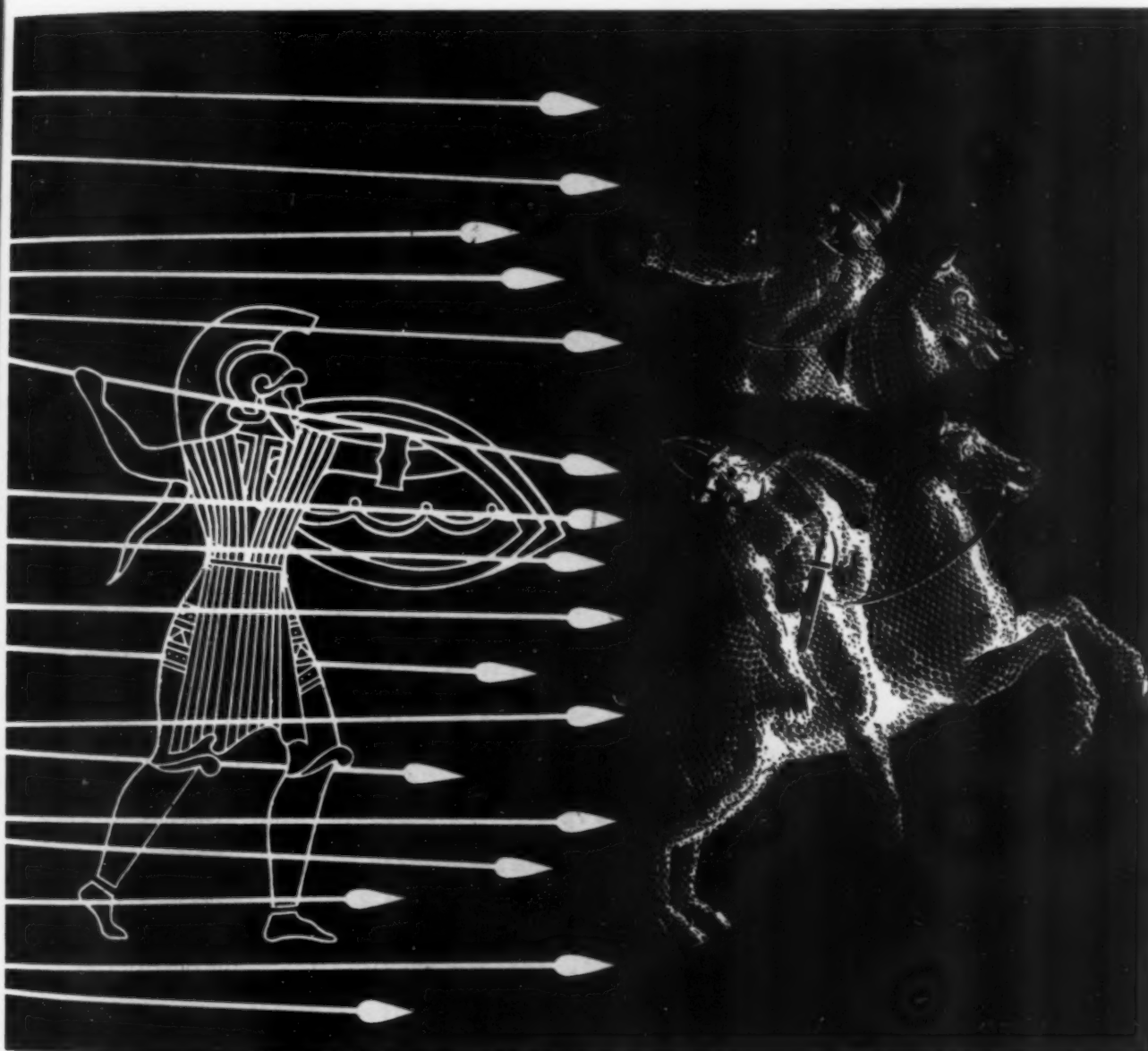
**Type 446**—The 27% Cr-Fe, while not discussed at length, is primarily considered as a heat resisting material. It has been used mainly in miscellaneous furnace parts, as oil burner nozzles, baffles, heat interchangers, and as stack dampers on furnaces; also as kiln liners, glass molds, pyrometer protection tubes and as rabbles on roasting furnaces. One of its principal uses has been as stationary soot blower elements in steam boilers. In the chemical or oil refining fields, it has been used in dehydrogenation equipment and for making butadiene for synthetic rubber from petroleum.



## THE MACEDONIAN SURPRISE PARTY

When the proud Persian hordes plunged headlong at Philip of Macedon's army, they were dumped into the minor leagues by an entirely new strategy, the phalanx: a solid wall of warriors sixteen ranks deep. Strength-in-depth withstood and defeated the impact of an over-confident enemy.

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MOLYBDIC OXIDE—BRIQUETTED OR CANNED • FERROMOLYBDENUM • "CALCIUM MOLYBDATE"  
CLIMAX FURNISHES AUTHORITATIVE ENGINEERING DATA ON MOLYBDENUM APPLICATIONS.

**Climax Molybdenum Company**  
500 Madison Avenue • New York City

## PERSONALS

Following his discharge from the Army where he served with the Manhattan Engineer District, Oak Ridge, Tenn., W. E. Butler is now a student and assistant in the metallurgical department, Polytechnic Institute of Brooklyn.

Hollis M. Walker, formerly with the Rock Island Railroad's forge shop, has accepted the position of forge shop superintendent at Johnston & Jennings Co., Cleveland.

Leonard E. Brown, a graduate of Armour College of Engineering, Illinois Institute of Technology, has been appointed project engineer of the Mathieson Alkali Works, Inc., Niagara Falls, N. Y.

Fred F. Sleeper has left his former position of chief standards and research engineer of Solar Precision Castings, Des Moines, Iowa, to return to the Lapointe Machine Tool Co., Hudson, Mass., as assistant chief engineer and lecturer. Mr. Sleeper had been with Lapointe from 1936 to 1942.

William J. Goodwin, after graduating from Missouri School of Mines and Metallurgy, has accepted a position in the Union Carbide & Carbon Research Laboratory, Niagara Falls, N. Y.

Lindsay Finney has been appointed general superintendent of Jenkins Brothers, Ltd., Montreal, Canada.

Sidney Siegel, formerly employed as a staff associate at Massachusetts Institute of Technology, has accepted a position as metallurgist for the General Plate Division of the Metals & Controls Corp., Attleboro, Mass.

Upon release from active duty in the Navy, Thomas E. Gregory has become associated with the Baldwin Locomotive Works, Eddystone, Pa., as foundry metallurgist.

L. G. Klinker, formerly with the Army Ordnance Division, is now a civilian and working as chief engineer of the metals refining division of the Glidden Co. He received a distinguished service citation for his work in the Ordnance Division.

A. F. Eggleton, recently released from the Army, has joined Joseph T. Ryerson & Son, Inc., as a salesman, special steels division, Chicago office.

Oil Well Supply Co. announces the appointment of T. C. Tweedie as manager of the subsurface department, Gulf Coast Division, Houston, Texas.

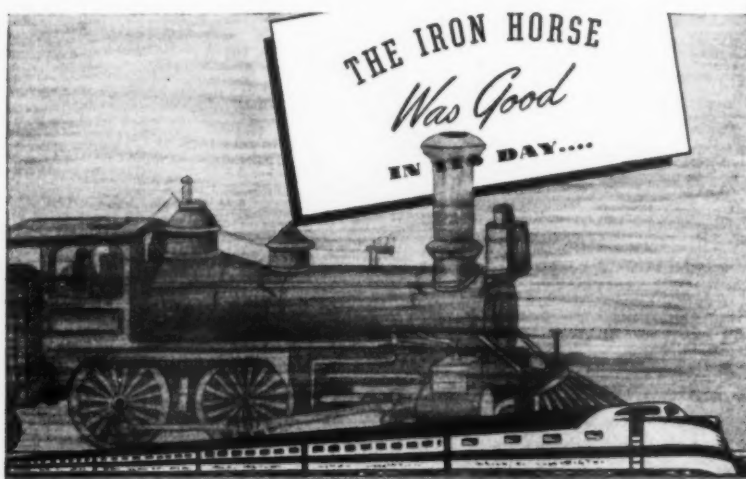
After two years in the Army, Marvin S. Hochberg has returned to Milprint, Inc., Milwaukee, as research and development chemist.

The United States Navy has transferred Merle F. Chapman to the Naval Air Technical Training Center, Jacksonville, Fla., where he will serve as instructional aids officer.

A. E. Zeisel, formerly assistant to president in charge of sales, Eutectic Welding Alloys Co., has been promoted to vice-president in charge of sales.

D. C. Winburn is continuing with the Manhattan District at Los Alamos, New Mexico, as a civilian at the termination of his Army service career.

After four years in the U. S. Navy, metallurgical research division of the Bureau of Ships, Bernard O. Brouk has returned to the National Bearing Division, American Brake Shoe Co., St. Louis, Mo., as sales engineer.



*BUT...*

It would soon be left far behind in any contest of speed with the Diesel, electric and steam locomotives of the present. Not only speed, but ease, economy and simplicity of control are the hallmarks of modern rail transportation. With

**CHEMICALS**  
**ACP**  
**PROCESSES**

**RUST PROOFING AND PAINT BONDING**

*Granadine*  
*Duridine*  
*Alidine*  
*Lithoderm*  
*Thermal-Granadine*

**RUST REMOVING AND PREVENTING**

*Deoxidine*  
*Peraline*

**PICKLING ACID INHIBITORS**

*Rodine*

## Duridine

the ACP double-action metal cleaner and phosphatizing chemical, these same advantages are in evidence.

DURIDINE, which can be used in the conventional power spray washer of mild steel construction, simultaneously cleans steel surfaces and coats them with a thin, tight phosphate film, well integrated with the parent metal. — The uniform, crystalline structure of this phosphate bond and its non-metallic, non-conductive properties make possible a firmly bonded and lustrous paint finish; and, in cases of accidental scratching or denting, rust creepage under the paint finish is prevented.

**AMERICAN CHEMICAL PAINT CO.**  
**AMBLER PENNA.**

# 5

## REVERE METALS

### Meet Strict Lock Requirements

★ ★ ★

Here is an example of the manner in which the wide variety of Revere Metals permits exact specification. In the manufacture of this lock *five* Revere Metals are employed. Here they are:

1. 70-30 Cartridge Brass for the dial flange
2. Commercial Bronze, 90%, for case, case lid and bolt
3. Heavy Leaded Brass for tumbler parts and other items, including dial, requiring exceptionally accurate machining
4. Free Cutting Brass in Rod and Extruded Shape, for the machined and knurled head, and for the angle bar
5. Forging Rod, for the tumbler driver

Selection and employment of these metals enabled the manufacturer to meet the many different requirements of fabrication methods, and at the same time assure strength, long life and reliable operation. Revere Metals perhaps can do as much for your own product. For cooperation in the choice and use of these metals, ask about the Revere Technical Advisory Service. Revere supplies mill products as follows: *Copper and Copper Alloys:* Sheet and Plate, Roll and Strip, Rod and Bar, Tube and Pipe, Extruded Shapes, Forgings — *Aluminum Alloys:* Tube, Extruded Shapes, Forgings — *Magnesium Alloys:* Sheet and Plate, Rod and Bar, Tube, Extruded Shapes, Forgings.

# REVERE

**COPPER AND BRASS INCORPORATED**

*Founded by Paul Revere in 1801*

230 Park Avenue, New York 17, New York

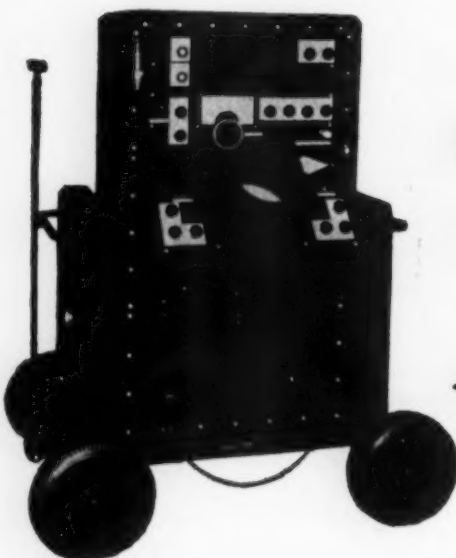
Mills: Baltimore, Md.; Chicago, Ill.; Detroit, Mich.; New Bedford, Mass.; Rome, N. Y.—Sales Offices in Principal Cities, Distributors Everywhere.



*Mosler combination lock, most of its parts fabricated of Revere Metals. Made by The Mosler Lock Company, Covington, Ky., the lock manufacturing division of The Mosler Safe Company, largest builders of safes and vaults in the world.*



# A Breakdown That Will Never Occur Foreseen by Sperry's Supersonic Reflectoscope!



This distorted pattern of light you see across the oscilloscope of a Sperry Supersonic Reflectoscope is indicating accurately and instantly the location of internal defects or flaws — flaws that, undetected, might have cost wasted hours in machining defective material — flaws that might even have caused service failures in the finished product!

Now in wide use throughout industry, the Supersonic Reflectoscope makes possible rapid, effective *non-destructive* testing for internal defects with complete safety — *better quality control*.

Inexpensive to operate, the Reflectoscope will search many metals and alloys to depths in the order of *ten feet*.

Write today for bulletins and data sheets which may help you to solve your quality control problems.

SP-103

**SPERRY  
PRODUCTS,  
INC.**

Willow Avenue at 15th Street  
Hoboken, New Jersey



## PERSONALS

Pemco Corp., Baltimore, Md., announces the election of **George H. Spencer-Strong**, director of research of the company since 1942, to the position of vice-president.

Crucible Steel Co. of America announces the following promotions at the Midland plant: **William R. Howell**, who has held several positions during his long tenure but most recently has been superintendent of inspection and metallurgy, has been appointed general superintendent. **Mathias J. Meinen**, previously superintendent of the electric furnace department, is now assistant general superintendent.

On the retirement of **Harvey W. Linhardt**, supervisor of the blast furnace department of Minnequa plant, Colorado Fuel and Iron Corp., **Robert R. Williams, Jr.**, formerly assistant supervisor, has been appointed to succeed him.

After graduating from the Missouri School of Mines and Metallurgy, **Kay Ikeuye** has been doing metallurgical work at the Institute for the Study of Metals, University of Chicago.

**B. R. Colby**, formerly lubricating engineer of Standard Oil Co., Atlanta, Ga., has been named manager of the lubricating department.

**H. A. Schwartz** has been awarded an honorary membership in the Belgium Foundrymen's Association. The only other scientist to receive this honor is the well-known French metallurgist, **Albert Portevin**.

Colorado Fuel & Iron Corp., Pueblo, Colo., announces the appointment of **Morton E. Weichsel**, formerly senior industrial engineer, to the post of superintendent of the industrial engineering department, a position left vacant by the retirement of **J. Rodney Irwin**. **Charles C. Tappero** has been appointed assistant superintendent of industrial engineers.

**Newton W. Richardson**, formerly sales manager for the Salem Engineering Co., in Pueblo, Colo., joined the Colorado Fuel & Iron Corp. as operating engineer on Jan. 1, and has now been appointed chief coordinating engineer.

**A. C. Meyers** has been appointed manager of the nickel department, Williams & Co., Inc., Pittsburgh, distributors for International Nickel Co., with warehouses in Pittsburgh, Cleveland and Cincinnati.



## ***Machinability Starts Here***

• A heat of Wisconsin steel pours into the ladle where it is Sulfite-Treated. That means it will be far more machinable than ordinary steel. And—physical properties remain completely satisfactory.

Solve your machining problems with Wisconsin's magic metal—Sulfite-Treated Steel. Check your requirements with our sales and metallurgical departments.

### **WISCONSIN STEEL COMPANY**

*(Affiliate of International Harvester Company)*

180 North Michigan Avenue

Chicago 1, Illinois

# **WISCONSIN Sulfite-Treated STEEL**

*April, 1947; Page 631*

# NOW— A QUALITY 2-KW INDUCTION HEATING UNIT

for only  
**\$650**



Never before a value like this new 2-KW bench model "Bombarder" or high frequency induction heater . . . for saving time and money in surface hardening, brazing, soldering, annealing and many other heat treating operations.

**Simple . . . Easy To Operate . . .  
Economical Standardization of Unit  
Makes This New Low Price Possible**

This compact induction heater saves space, yet performs with high efficiency. Operates from 110-volt line. Complete with foot switch and one heating coil made to customer's requirements. Work coil  $\frac{1}{2}$  to  $2\frac{1}{2}$  in. diameter. Unit will work with coil of one turn to a maximum of 20 turns. Cost, complete, only \$650. Immediate delivery from stock.

Scientific Electric Electronic Heaters are made in the following range of power: 1-3-5-7½-10-12½-15-18-25-40-60-80-100-250KW. — and range of frequency up to 300 Megs. depending on power required.

**Scientific Electric**  
DIVISION OF

"S" CORRUGATED QUENCHED GAP CO., 119 MONROE ST., GARFIELD, N. J.

## PERSONALS

Fred Thoman ☉, formerly plant superintendent for the Commercial Iron Works, is now general superintendent of the Northwest Marine Iron Works, Portland, Ore.

Ralph L. Freeman ☉ has resigned his position with the Western Electric Co., Chicago, to accept an appointment as assistant professor of metallurgy, department of mechanical engineering, Iowa State College, Ames, Iowa.

Clinton C. Hudson ☉ has been employed by Fairchild Aircraft Division, Fairchild Engine and Airplane Corp., Hagerstown, Md., as supervisor of metallurgical, chemical, physical testing, material and process, and X-ray laboratories.

James P. Bates ☉ has been appointed chief metallurgist of the Hyster Co. and will be in charge of materials specifications and heat treating for the company's three plants with headquarters in Portland, Ore. Mr. Bates was formerly with Pratt Whitney Aircraft Corp. and Westinghouse Electric Corp.

E. C. Babson ☉ has resigned from the Union Oil Co. and is now associated with the Peerless Pacific Co., Portland, Ore.

Walter M. Salmons ☉ has been appointed foreman of the forge shop of the Delaware Tool Steel Corp., Wilmington, Del.

On completion of his metallurgical engineering course at Rensselaer Polytechnic Institute, David A. Vermilyea ☉ has accepted a position as metallurgical engineer in the ammonia department of E. I. du Pont de Nemours and Co., Inc., at Belle, W. Va.

Henry K. Georgius ☉ has joined M. W. Kellogg Co., Jersey City, N. J., working in process design and development of rockets.

D. W. McDowell, Jr., ☉, formerly associated with metals research laboratory, Carnegie Institute of Technology, is now on the teaching staff of Iowa State College, Ames, Iowa.

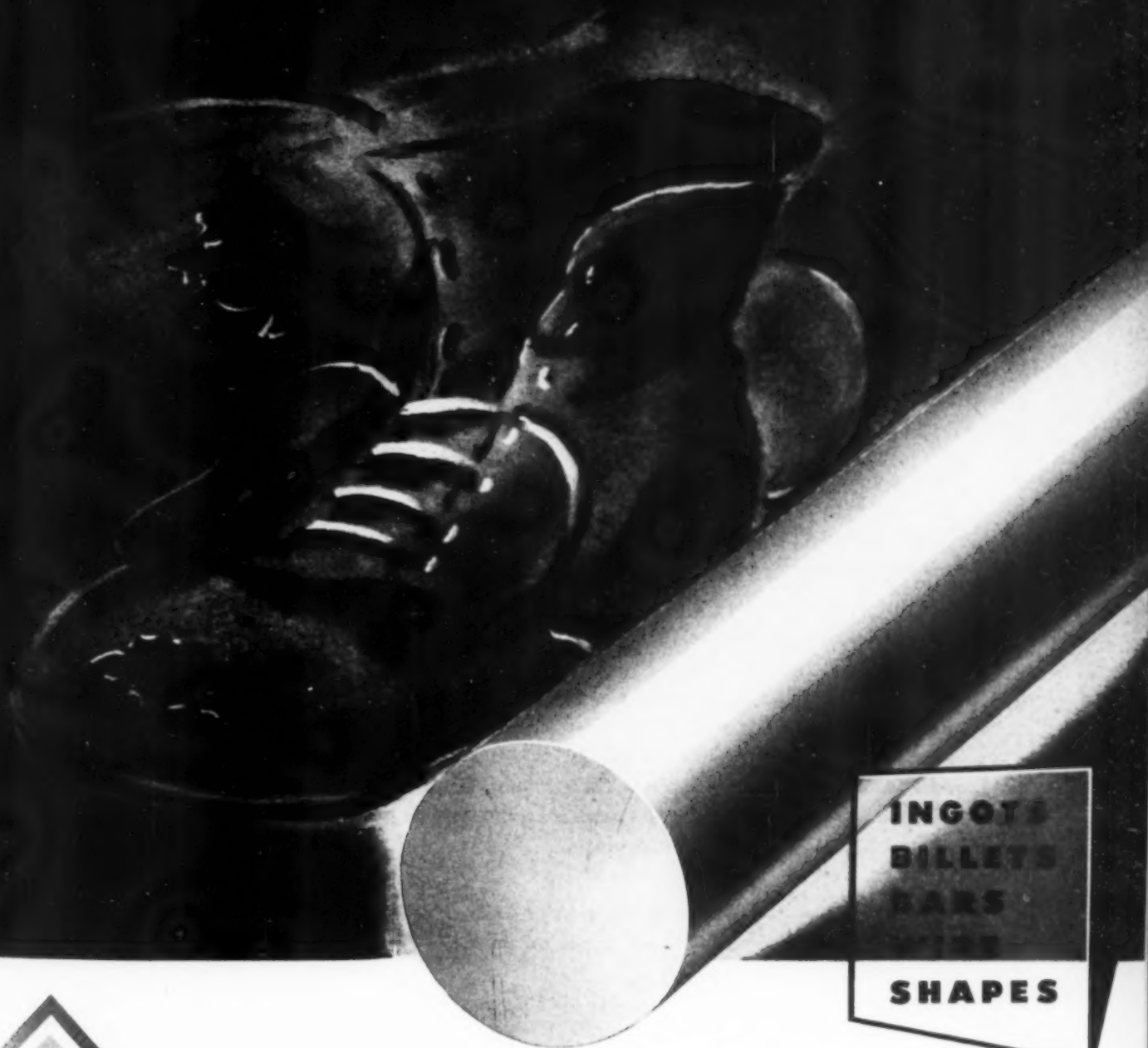
David J. Greetzman ☉ has established a consulting practice in the electroplating and allied fields at New Rochelle, N. Y.

Resigning as vice-president and director of Marmon-Herrington Co., Inc., Robert C. Wallace ☉ has accepted the position of executive engineer of Diamond T Motor Car Co., Chicago.



**JOSLYN STAINLESS STEELS**  
**YOUR SAFEGUARD AGAINST...**

*Abrasion*



**INGOTS  
BILLETS  
BARS  
PIPE  
SHAPES**



Joslyn Stainless Steels are available in all AISI types. Write for Stock List—published monthly.

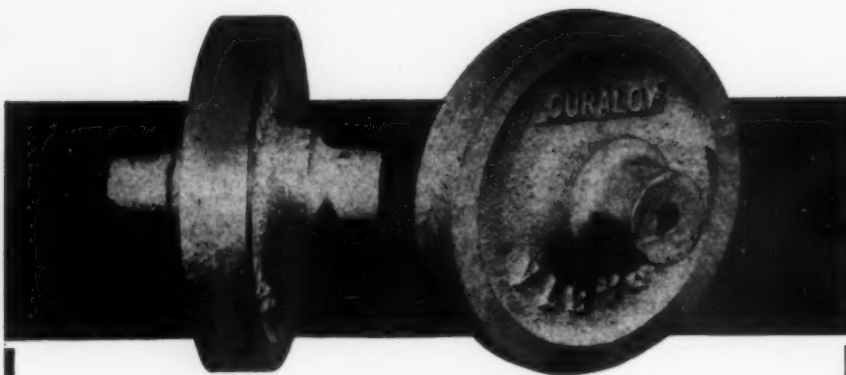
**Joslyn Stainless Steels**

**JOSLYN MFG. AND SUPPLY CO., FT. WAYNE 6, IND.**

**ELECTRIC FURNACES. HOT AND COLD FINISHING MILLS. LOCATED AT FORT WAYNE, IND.**

# DURALLOY

**HIGH ALLOY CAST ROLLER . . . Weight 17<sup>1</sup>/<sub>10</sub> pounds**



25% Chromium and 12% Nickel . . . these are the principal elements selected to provide these small rollers with the heat-resisting strength to carry the heavy loads in an annealing furnace.

But there's more to producing consistently sound castings than knowing which and how much of the several alloying elements to use. High alloy foundry experience is even more important. Shop facilities as well as quality and conditioning of the molding sand used count heavily toward satisfactory castings. These and other important contributing factors can be found in the background of the casting service offered by Duraloy Metallurgists and Foundrymen.

**We would like to produce your high alloy castings. May we quote on your next requirements?**

**THE DURALLOY COMPANY**

Office and Plant: Scarsdale, N. Y. • Eastern Office: 12 East 41st Street, New York 17, N. Y.

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4-DU-2

## PERSONALS

E. F. Losco ☉ has been transferred by Westinghouse Electric Corp., which he joined a year ago on his release from the U. S. Army, from the materials engineering department to the Westinghouse Research Laboratories in East Pittsburgh.

Quaker Chemical Products Corp. has promoted Robert S. Moore ☉ from development chemist in the research and development division to district supervisor of the technical service division, Detroit.

Stanley G. Kroto ☉ has been promoted by Rolock, Inc., Fairfield, Conn., from plant engineer to manager of the new Cleveland sales office.

Edgar S. Byron ☉, formerly senior fellow at Mellon Institute, has been appointed staff supervisor of the molybdenum development division at Westinghouse Electric Corp.

A. J. Karam ☉ is now a metallurgical engineer in the research department, magnesium division, Dow Chemical Co., Midland, Mich.

Joseph Urbano ☉ has opened a tool and die shop under the name of Westbrook Industries, Inc., Newark, N. J.

D. W. McDevitt ☉ has been placed in charge of the new offices of the DuBois Co. in Green Bay, Wis.

Greer Ellis ☉ is now consultant on strength problems for the Magnaflex Corp. in the eastern territory.

Electro Refractories & Alloys Corp., Buffalo, N. Y., announces the promotion of R. C. Wolfong ☉ to sales manager of the abrasive division. He was previously abrasive engineer in the Pittsburgh area.

George H. Holladay, Jr., ☉ is now secretary, treasurer and member of the board of directors of Reliance Chemical Co., Inc., Chicago.

George F. Landgraf ☉, formerly metallurgist and precipitator engineer of Koppers Co., has become associated with the Pittsburgh Range Co., Inc., McKees Rocks, Pa., as vice-president in charge of engineering.

A. E. Dwight ☉ has entered the graduate school of the University of Michigan to work toward an advanced degree in metallurgy.

G. J. Bau ☉, formerly with Maysteel Products, Inc., is now methods engineer for Milwaukee Gear Co.

# NOW

*...color film  
you can process  
yourself*



With KODAK EKTACHROME... you can see full-color transparencies while the subject is still set up

When you want to judge results of color photography without delay, in your own darkroom... that's the time you appreciate Kodak Ektachrome!

With it, you have quick, convincing proof that you've accurately pictured the fine color differences that tell significant stories in industrial research and control. For instance...

If you're a metallurgist, Ektachrome enables you to picture quickly, and study at leisure, colors brought out by etchants and polarized light—colors that identify inclusions, segregate phases, oxidation and diffusion zones.

If you're a design engineer doing photoelastic stress analysis... a chemist or mineralogist who uses the petrographic microscope... if you feel a color transparency would be desirable in any situation from raw material to finished product... Ektachrome can give it to you within less than two hours.

Ask your Kodak dealer for Ektachrome. He has this quick-processing color film in all the standard sheet film sizes... together with complete instructions and processing chemicals that are just as safe as ordinary developers.

**EASTMAN KODAK COMPANY**  
Rochester 4, N. Y.

**Kodak**



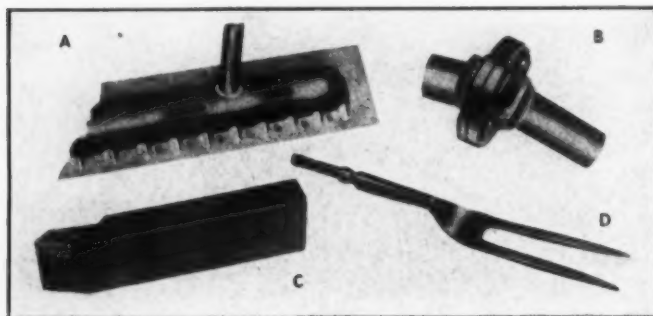
*Give  
Your Production  
a Lift with*



# NO. 217 SILVER BRAZING ALLOY

APW No. 217 is tops for low temperature production brazing of steel, stainless steel, alloy steel, copper, brass, bronze, Inconel and monel metal. Only small amounts are needed to make clean, sound, leak-proof joints.

Tested and approved by leading manufacturers... here are a few typical applications:



A-Stainless Steel & Copper Refrigerator Sub-Assembly. B-Brazed Steel Universal joint. C-Carbide Tool Tip brazed to Shank. D-Stainless Steel Fork Assembly.

APW NO. 217 ALLOY IS FURNISHED IN WIRE COILS, STRIP, SHEET, WIRE RINGS, WASHERS, DISCS AND SPECIAL INSERTS.

ANY FORM • ANY SIZE  
ANY QUANTITY.

THERE'S AN APW LOW TEMPERATURE  
SILVER BRAZING ALLOY FOR  
EVERY PURPOSE

## APW No. 369 PASTE FLUX

Gives maximum protection to metal surfaces being joined and actively promotes flow of molten alloy. Easily soluble in hot water.



Send for our new folder 45W.

## THE AMERICAN PLATINUM WORKS

231 NEW JERSEY R.R. AVE., NEWARK 5, N. J.

PRECIOUS METALS SINCE 1875

## PERSONALS

E. F. Houghton & Co. has transferred R. J. Rathbone from the Detroit area to the northwestern Ohio area, where he will sell and service all Houghton products.

John E. Shoemaker has left Standard Steel Spring Co. to accept the position of metallurgist on the staff of the Ordark Research Project of the University of Arkansas, Fayetteville, Ark.

H. R. Lowers has left his position as laboratory engineer with Chrysler Corp. to accept a position as instructor in the mechanical engineering department at Ohio State University, Columbus, Ohio.

Resigning his position as district manager for the Beryllium Corp., Thomas F. Davis has joined the sales staff of Peter A. Frasse & Co., Inc., Philadelphia.

William L. Allman is now employed by Socony-Vacuum Oil Co. as a lubrication engineer, industrial department, Albany, N. Y., division.

After completing his service in the U. S. Navy, Paul B. Payne is back with the Dearborn Chemical Co. with offices in Indianapolis.

Fred C. Robertshaw, Jr., formerly assistant mill metallurgist at Allegheny Ludlum Steel Corp., is now at the metallurgical section of the Thomson laboratory of General Electric Co., Lynn, Mass.

W. H. Meyer, formerly field metallurgist for Copperweld Steel Co., is now metallurgist and sales engineer for Ohio Industrial Steel, Dayton, Ohio.

Leonard Epstein joined the Chance Vought Aircraft Division, United Aircraft, Stratford, Conn., on his release from the Army. He is at present connected with the engineering design group.

J. W. Doll has been transferred by Timken Roller Bearing Co., Steel & Tube Division, from the Los Angeles and West Coast districts to Canton, Ohio, as manager of warehouse products.

Andrew M. Kazimer, formerly employed by Goodyear Aircraft Corp., has joined the Superior Zinc Corp., Bristol, Pa., as research engineer.

Wheelco Instruments Co. announces the appointment of E. W. Heffernan as manager of its new Philadelphia sales and service office.

# LEPEL Spark-Gap CONVERTERS

No. 3



**JOINING BRASS STAMPINGS  
5 TIMES FASTER**

The two halves of handles for vanity mirrors were being joined by flame heating, using a silver alloy. The operation was becoming a bottle-neck — one *skilled operator* could complete less than 400 per day.

Lepel Laboratories developed this jig and heating coil for use with a spark-gap converter. Handles are now produced with less discoloration; joints are always uniform. Cleaning is appreciably reduced and rejects are eliminated. Cool, clean working conditions greatly improved the operation. Outstanding feature: with a single 15-kw Lepel unit and two jigs and coils, one *unskilled operator* produces 240 handles *per hour*.

## 4 HOURS GRINDING TIME SAVED BY INDUCTION-HARDENING LEAD SCREWS

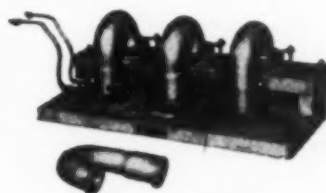
Before induction hardening was tried, a large machine-tool manufacturer ground the threads of 1½-in. diameter lead screws from bars already hardened to 47-49 Rockwell C. This was necessary to avoid lead

elongation in conventional heat treating. Grinding time was seven hours.

Now progressive *induction* heating, with Lepel equipment, is *used* to harden threads, only, as shown in etched cut-away. Service



life is improved by the 55 to 60 Rockwell C hardness obtained on thread surfaces. Ductility is maintained at the thread roots. Threads are cut before hardening; average lead elongation of .0027 in. in a 42-in. screw is easily corrected by a quick finish grind. Machining time is now two to three hours.



**6 JOINTS SOLDERED  
EVERY 24 SECONDS**

Soldering threaded connectors to brass elbows is an ideal job for a Lepel Induction Heating Unit. With a 15-kw unit, three complete elbows — six joints — can be soldered in 24 seconds. With two jigs and lead coils, operation can be continuous, producing 450 elbows per hour. Discoloration is eliminated. High-frequency heating is not only faster and requires no skilled labor — it is cleaner, cooler, eliminates fire hazard and requires less space.



**HARDEN**



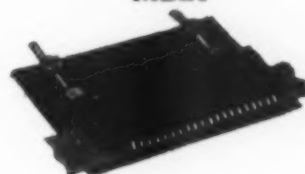
**SOLDER**



**BRAZE**



**MELT**



**ANNEAL  
STRESS RELIEVE  
PREHEAT  
NORMALIZE**

IF YOU HAVE A PROBLEM in joining, heat treating or melting of ferrous or non-ferrous metals, chances are that a Lepel High-Frequency Induction Heating Unit can help you to do a better, faster, more economical job. Lepel metallurgists and field engineers will be glad to make a thorough study of your specific problem, and help you put the right, compact, movable Lepel unit on the job. Call, or write, Lepel High Frequency Laboratories, Inc., 39 West 60th Street, New York 23, N. Y.

NOTE: Send for our 32-page catalog which gives a complete story on what high-frequency heating can do for you.

PIONEERS IN INDUCTION HEATING



... ferrous and  
non-ferrous metals  
with the SAME  
Lepel unit

## "FALLS BRAND" ALLOYS

AMERICA'S LARGEST PRODUCERS OF ALLOYS

*"Falls"*

### No. 14 ALLOY

*makes*  
**Solid Brass and Bronze**  
**Castings**

If you make bronze castings to withstand pressure, use "FALLS" No. 14 ALLOY and save 5 to 50% of the castings that would be rejected on account of leakage after machining.

- ... reduces casting losses due to porosity in composition, valve metal, bronzes, etc.
- ... deoxidizes — by reducing Metallic Oxides.
- ... densifies—by producing a close grained structure.

*Write for complete details*

## NIAGARA FALLS

**Smelting & Refining Division**

Continental United Industries Co., Inc.  
BUFFALO 17, NEW YORK

## TRIBO-ELECTRIC SORTING\*

AN INSTRUMENT has been developed for electrically sorting and identifying pure metals, steels and nonferrous alloys known as the Metalsorter. The test is nondestructive, unaffected by variables in the size or shape of the metal, and rugged enough to be used in the shop.

The tribo-electric effect in metals is the basis of this sorting method. Fundamentally, tribo-electricity is simply friction electricity created when two chemically dissimilar substances are rubbed together. The use of the tribo-electric effect for metal sorting is accomplished by reciprocating a standard reference specimen of known character against the surface of the unknown piece and registering the potential developed, if any. Obviously, if no potential is developed, the two pieces are metallurgically identical.

The nature of the dissimilarity, if a potential is developed, is indicated by the polarity and size of the potential, providing preliminary tests involving the types of metals on hand have been made. Since the mechanical destruction of reference standards during testing is negligible, the proper standards, having once been determined and selected, may be used indefinitely.

When dissimilar specimens are compared tribo-electrically, the potential registered is a composite result of several metallurgical variables. That is, a tribo-electric potential can be ascribed to a difference in chemical composition only when it is known that the constitution of the two pieces being compared is of the same order. Shifts in constitution may be detected and defined when it is known that the chemical composition of the pieces is the same. Because the tribo-electric effect is confined purely to the surfaces of the materials being tested, a potential indication representative of the main composition of the part will be obtained only if the composition of the surface is the same as that of the core.

The fields of application for the Metalsorter are not restricted to any one class of metals although some types of analyses are tribo-

(Continued on page 640)

\*Abstracted from "Sorting Metals by Tribo-Electrification", by Antony Doscheck. *Steel*, Dec. 24, 1945, p. 106 to 110.



# Remove obstacles

# like these...



Have you a problem which graphite in a liquid carrier can solve? "dag" colloidal graphite dispersed in many liquids has offered novel solutions to many vexing problems for scores of industries.

You know many of "dag" colloidal graphite's successful applications, but you will discover other equally helpful applications by reading the booklets listed below. Acheson Colloids Corporation's technical research and advisory service is continuously studying industrial problems and developing new uses of "dag" colloidal graphite to remove these problems. Return the coupon and find out how you can satisfactorily deal with your problems.

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This new literature on "dag" colloidal graphite is yours for the asking:

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- ☐ **421** Facts about "dag" colloidal graphite for ASSEMBLING AND RUNNING-IN ENGINES AND MACHINERY.
- ☐ **422** Facts about "dag" colloidal graphite as a PARTING COMPOUND.
- ☐ **423** Facts about "dag" colloidal graphite as a HIGH TEMPERATURE LUBRICANT.
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A-D-1

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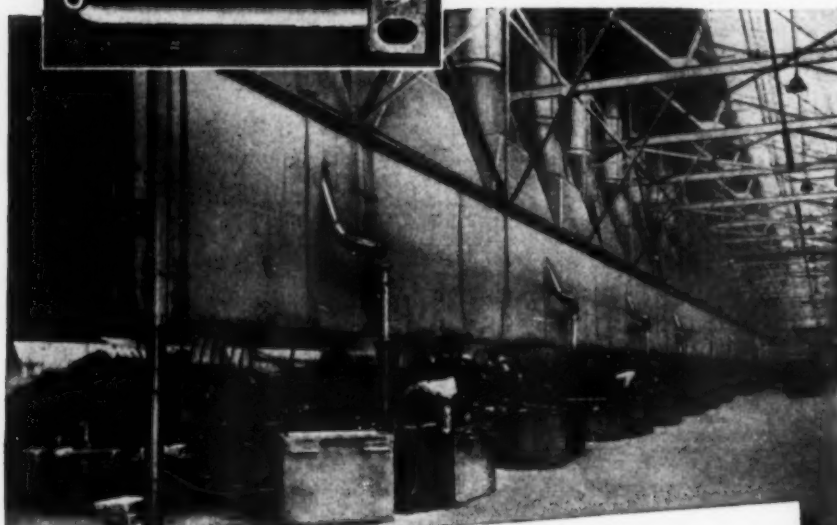
NAME \_\_\_\_\_  
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ADDRESS \_\_\_\_\_  
ZONE No. \_\_\_\_\_ STATE \_\_\_\_\_  
OUR PRESENT OIL SUPPLIER IS \_\_\_\_\_

(Lubricants containing "dag" colloidal graphite are available from major oil companies.)



"Not only to serve today, but to anticipate tomorrow"

Wm. B. Given, Jr.



## MEEHANITE CASTINGS as made by BRAKE SHOE

a "below-the-surface"  
selection in tin plate immersion melting

**W**HEN Kemp immersion melting equipment was decided upon for one of the world's longest lines of tin-stacks, the choice of heating element was carefully made. The tin plating of steel demanded the travel of flue gas through a complete tubular loop below the surface of the metal bath. Determining the best metal for this loop called for full consideration of strength and pressure tightness as well as resistance to thermal shock due to intermittent heating.

The answer: structurally sound non-porous castings of heat-resisting Meehanite, free from all foundry defects and suitable for immersion in dense liquids. The practical benefits: a method was made possible that surpassed external-firing practice by consuming less gas, controlling temperatures more closely, reducing dross formation drastically and increasing production rate.

As in this case of The C. M. Kemp Mfg. Co. of Baltimore, Md., you can get a type of Meehanite which closely fits a specific set of job requirements in its metallurgical content and combination of performance characteristics. Meehanite castings as made by Brake Shoe give you the further assurance of an unequalled foundry background.

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## SORTING

(Continued from page 638)

electrically more powerful than are others. Many types of steels, brasses, bronzes and aluminum alloys can be sorted. As a specific example, forgings of N.E. 8620 and 9450 were sorted at a rate of about 500 separations an hour by the use of a standard of N.E. 8620. Three different operators worked the equipment after about 15 min. of instruction.

## ISOTOPES AS TRACERS\*

**A** SMALL AMOUNT of suitably chosen radioactive isotope added to one of the substances taking part in a physical or chemical process makes it possible to follow the atoms of that element right through the process, to detect their final location and to determine the distribution by means of their radioactivity or difference in atomic weight. The isotope will thus furnish information about the nature and progress of the process in question. This is especially true for processes in which there is an exchange of identical particles. However, it is applicable to many other investigations because of its extremely high sensitivity and the ease with which it answers questions.

The following examples show how this isotope tracer method may be applied to metallurgical problems:

The tracer method will give an accurate check on the amount of phosphorus in steel at any stage of production. If a small amount of radioactive phosphorus is added at the beginning of the process, this is distributed uniformly throughout the melt so that the ratio between natural phosphorus and radioactive phosphorus is the same everywhere—in the slag, furnace or ladle lining and molten metal. A decrease in radioactive phosphorus in the melt will, therefore, indicate a proportional decrease in the natural phosphorus. An electron counter can give the radioactivity of samples of the melt in a few seconds, and consequently a close and accurate check may be kept on phosphorus content

(Continued on page 642)

\*Abstracted from "The Use of Isotopes as Tracers", by A. H. W. Aten, Jr., and F. A. Heyn. *Philips Technical Review*, Oct. 1946, p. 296.

# HOUGHTON ANNOUNCES A NEW SERIES OF METAL CLEANERS

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After a two-year study, we perfected new formulae for each job of cleaning metal surfaces. Results: a better job, *faster*—reducing cleaning time to less than half, as compared to pre-war cleaners. That, in a few words, is the Houghto-Clean "200" story; for more, send the coupon.

## 82 years' experience

Houghton is no new-comer in metal processing. Its record dates back to 1865; through those many years it has pioneered in cleaners, cut-

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ting oils, rust preventives, heat treating salts; quenching oils and drawing compounds. Houghton service on all of these is highly regarded by metal-men. E. F. HOUGHTON & CO., 303 W. Lehigh Avenue, Philadelphia 33, Pa.

\*Ultra-violet light was used to evaluate each of the 17 new Houghto-Cleans. Residues remaining on metal plates after various timed periods of cleaning glow with fluorescence, revealing what daylight vision cannot detect.

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## ISOTOPEs

(Continued from page 640)

through the whole process. Of course, phosphorus could be determined by chemical analysis, but this radioactive isotope tracer method is much quicker and easier.

Mercury in excess of  $10^{-4}$  g. per cu.m. of air is injurious to health, but this minute quantity is difficult to determine because chemical analysis is unavailing. The following test was used in one application to check the exact amount of mercury in the air: Two liters of air were placed in contact with a few drops of mercury—the amount that had been in use under an actual condition being duplicated. This air was drawn off and passed over a metal plate kept at the temperature of liquid air, where practically all of the mercury absorbed by the air was condensed. Since the mercury used had contained a predetermined percentage of radioactive isotope, the radioactivity of the plate was a record of the amount of mercury that had been contained in the air that was passed over the plate. A concentration of  $5 \times 10^{-6}$  g. per cu.m. was detectable.

Very fine cracks in metal surfaces can be detected and localized by applying a greasy paste containing a radioactive substance to the surface of the metal under high pressure. After the surface is cleaned, the paste left in the cracks can be shown on an autoradiogram.

Finally, the tracer method offers the best opportunity to study the transfer of identical particles. Where friction exists and like metals transfer from one piece to another, the amounts are so small as to be practically unmeasurable chemically. However, if one surface is activated to a known degree, the quantity of transfer between the two surfaces through friction can be determined for amounts as small as  $10^{-10}$  g. By means of a radiogram the distribution of the transferred atoms may also be located. Since transfer usually takes place during small jerks in the motion, the influence of factors such as pressure, hardness of surface, and lubrication can be studied. Because this transfer is so slight, works both ways, and the particles are identical, it cannot be studied in another way.

The tracer method can also be applied with nonradioactive isotopes, but not nearly so easily. Here the difference in atomic weight is used as the test.

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## GAS TURBINE ALLOY\*

TO MEET the demand for a superior high temperature alloy for turbosupercharger and gas turbine applications, the Timken Roller Bearing Co. developed the 16-25-6 alloy with the following analysis:

Carbon, 0.12% max.  
Manganese, 2.00% max.  
Silicon, 1.00% max.  
Chromium, 15.00 to 17.00%  
Nickel, 24.00 to 27.00%  
Molybdenum, 5.50 to 7.00%  
Nitrogen, 0.10 to 0.20%

Forging and rolling presented considerable difficulties but a successful forging technique was finally developed. It is necessary to use hydraulic forging presses to reduce the ingots to a billet size which can then be rolled.

The 16-25-6 alloy is austenitic and nonmagnetic. As hot rolled, its structure consists of austenite grains and another phase which

\*Abstracted from "16-25-6 Alloy for Gas Turbines", by Martin Fleischmann, *Iron Age*, Jan. 17, 1946, p. 44 to 53; Jan. 24, 1946, p. 50 to 60.

has the appearance of carbides dispersed in banded form. Solution of the carbides begins at 2000° F. and is practically completed at 2150° F. On reheating material quenched from 2150° F., precipitation occurs at 1200 to 1500° F. Room-temperature tensile tests were made to show the effect of varying austenizing temperatures and of varying tempering temperatures. The highest yield strength and tensile strength are found in the hot rolled material. Tempering the hot rolled material not only lowers the yield strength but also markedly decreases the exceptionally high ductility values of the as-rolled material. The series of quenched samples reveals that maximum ductility is obtained by quenching from above 2150° F. However, this treatment causes a considerable drop in yield strength and some decrease in tensile strength. Solution quenched samples tempered for 12 hr. at 1200 to 1600° F. show the effect of precipitation hardening which reaches a maximum at 1500° F.

Since this alloy is austenitic, it cannot be hardened by standard

(Continued on page 646)

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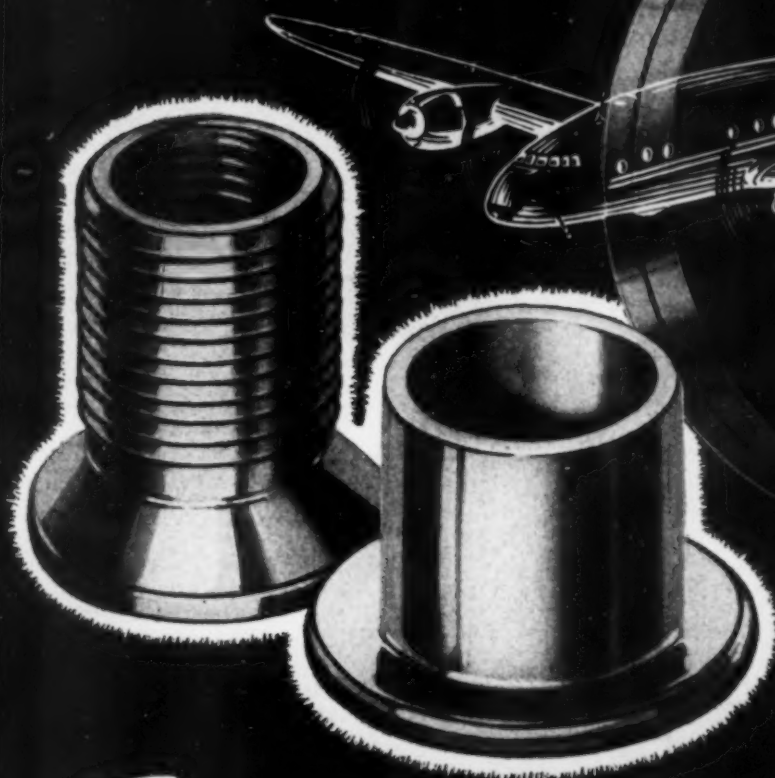
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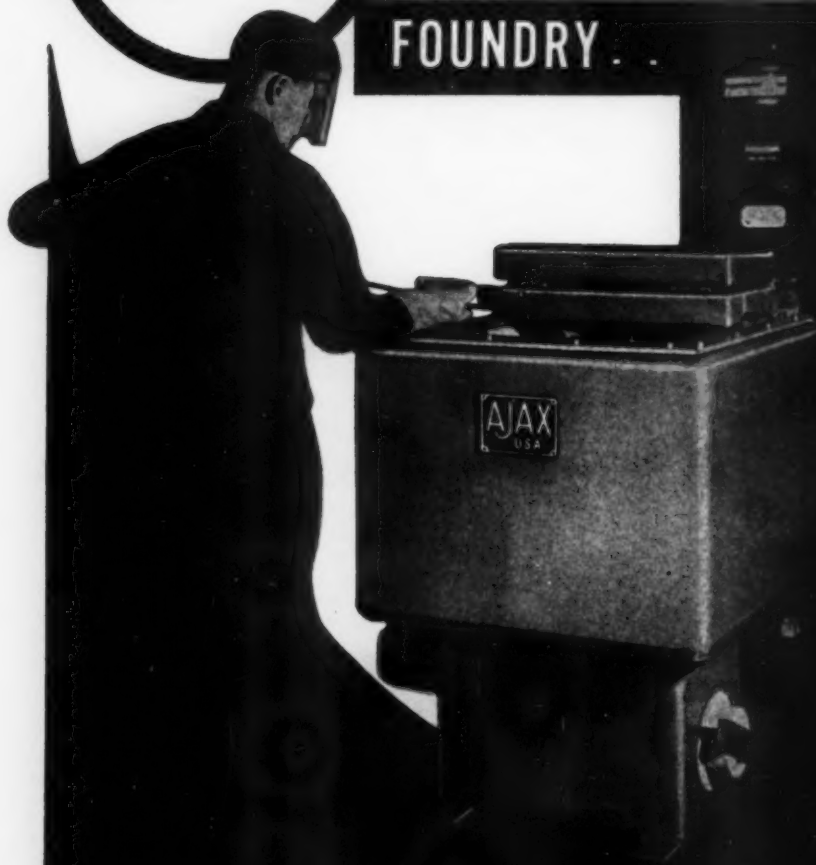
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## TURBINE ALLOY

(Continued from page 644)

thermal treatments. Its physical properties, however, are materially affected by cold work which is effective to different degrees up to temperatures above 1700° F. Cold working at room temperature causes a uniform increase in room temperature yield and tensile strength and a fairly uniform decrease in ductility. The specimens cold worked from the hot rolled condition give higher strength properties than the solution treated bars given an equivalent amount of cold work. The ductility values of the hot rolled and cold worked material are somewhat lower than those of the quenched and cold worked specimens.

The effect of subsequent tempering was also investigated. About 20 hr. at tempering temperature are required to reach an apparent equilibrium. The loss in hardness by tempering at 1200° F. for 72 hr. is only about Rockwell C-5. The hardness of solution quenched material may be substantially increased by tempering without previous cold work. For a tempering time of 10 hr., a maximum increase in hardness (Rockwell C-5 to 18) is obtained by tempering at 1400° F.

Stress-rupture tests indicate the superiority of the 16-25-6 alloy. For example, a load of 6000 psi. at 1500° F. would cause rupture of a steel with 5% chromium, 0.5% molybdenum and 1.50% silicon in 12 min., of an 18-8 in 100 hr., while the 16-25-6 would not rupture for more than a year. At least for long rupture times at temperatures over 1200° F., little if any benefit may be gained by previous cold working and precipitation hardening. On the other hand, precipitation hardening and cold working lower the creep rate at least up to 1300° F. At 1400° F., the 16-25-6 requires a load of 10,000 psi. for a creep rate of 0.1% in 1000 hr., while a load under 3000 psi. will give the same rate for 18-8.

In the mass production of turbo-supercharger wheels from this alloy, two distinct operations were required: hot working and cold working. The cold working imparts high room-temperature yield strength values which will be retained to a large extent during the limited service life at elevated temperatures.